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Remote Sensing of Mine Waste

By C. M. K. Boldt and B. J. Scheibner



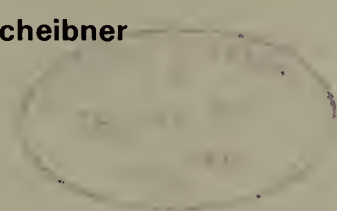
UNITED STATES DEPARTMENT OF THE INTERIOR



Information Circular 9152

Remote Sensing of Mine Waste

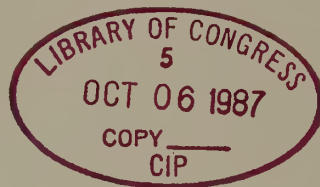
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A•h	ampere hour	in	inch
bps	bits per second	m	meter
ft	foot	st	short ton
h	hour	V	volt
ha	hectare	yr	year

REMOTE SENSING OF MINE WASTE

By C. M. K. Boldt¹ and B. J. Scheibner²

ABSTRACT

This report summarizes five separate Bureau of Mines contract studies on the use of aerial photogrammetry, satellite transmission of in situ instrumentation information, and satellite imagery to monitor and update mine waste embankment data. The equipment used, methods applied, results, recommendations, and cost analyses are presented along with a bibliography of related investigations.

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²Geologist.

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INTRODUCTION

Remote sensing can encompass a broad spectrum of techniques including (1) photogrammetry, which uses aerial photography to obtain cadastral surveys, (2) electro-optical systems, which transform electromagnetic radiation into electrical signals to produce images, and (3) imaging and nonimaging sensors, which measure an object's radiation (1).³ Remote sensing, as it relates to mine waste embankment monitoring, is the gathering of information without direct human contact. This report concerns itself with aerial photogrammetry and the use of satellites either as a communications transmitter of in situ instrumentation data or for imagery. The studies discussed in this report (2, 4, 6-8) were completed under contract with the Bureau of Mines, Spokane Research Center, Spokane, WA.

Existing inspection techniques used by Mine Safety and Health Administration (MSHA) personnel consist of individual on-site visits. Typically, only a limited number of sites per day can be inspected owing to travel time requirements and the size or ruggedness of the terrain. Aerial photogrammetry allows inspection of a number of sites and provides documented, sequential evidence over time of an embankment's surface changes, such as erosion, volume changes, and drainage maintenance; however, it may not always detect sites of minor ground

movement. Satellite monitoring allows the embankment conditions data to be read on demand at even the most remote sites, but image detection resolution is limited. Even with such limitations, remote sensing offers many advantages; therefore, remote sensing studies were initiated by the Bureau to determine their value for improving inspection techniques and monitoring effectiveness.

This summary of remote sensing investigations is divided into three major sections: Aerial Monitoring, Remote Data Transmission, and Satellite Imagery. In the "Aerial Monitoring" section, study 1 describes the use and results of aerial photogrammetry on an actively moving landslide in Oregon and on two coal refuse sites in West Virginia; study 2 used a different technique to monitor 15 coal waste sites in West Virginia and Kentucky. Under "Remote Data Transmission," phases 1 and 2 describe the use and results of various in-place instruments, such as inclinometers and piezometers, and the effectiveness with which their data can be transmitted from a remote site to a collection center anywhere in the country via satellite. The "Satellite Imagery" section assesses the effectiveness of using Landsat photos of mine waste locations to update and upgrade existing mine waste inventory data.

AERIAL MONITORING

STUDY 1

Since 1974, the Bureau of Mines has been interested in using remote sensing techniques to improve coal waste site monitoring capabilities (8). In 1974, the Bureau awarded a contract to CH2M Hill to look at the feasibility of developing a fast, reliable, and effective method of measuring the stability of coal waste embankments by remote means. Various techniques were categorized and

tabulated according to their ability to meet these requirements (fig. 1). Aerial photogrammetry was determined to be the most promising technique for monitoring coal waste embankments.

Description of Work

After the aerial photogrammetric method had been chosen, the technique was applied to actual field conditions. To be able to obtain on-site measurements as well as the aerial photographs, it was necessary to have a site that was accessible without disturbing production. Consequently, an active landslide near

³Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Monitoring methods																					
Remote sensing					Conventional					Simplified "conventional" devices											
Photogrammetry	Radar	Scanning			Field strength measuring devices	Geophysical	Ordinary surveying	Extensometers	Inclinometer	Water and flumes	Stream gaging	Sampling	Piezometers	Visual observations	Qualitative slope indicators	Simple extensometers	Weirs and flumes	Simple visual range lines	Repetitive photographs	Surface tiltmeters	Innovative
		Multispectral	Thermal infrared	Radiometry (long wave)																	
Various emulations	Various filters				●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
					●	●	●	●	●	●	●	●	●	●	●	▲	●	●	●	●	●
					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
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KEY
 Nap Not applicable or unknown
 ● Suitable
 ▲ Possibly suitable
 X Not suitable

FIGURE 1.—Matrix of monitoring methods.

Evaluators		Monitoring methods																									
		Remote sensing										Conventional							Simplified "conventional" devices								
		Photogrammetry		Scanning				Radar	Geophysical			Ordinary surveying	Extensometers	Inclinometer	Weirs and flumes	Stream gauging	Piezometers	Visual observations	Qualitative slope indicators	Simple extensometers	Weirs and flumes	Simple visual range lines	Repetitive photographs	Surface tiltmeters	Innovative		
Embankment stability indicators	External stability indicators	Various emulations	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		Various tiltmeters	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		Excessive slope	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		Excessive height	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		Too undercutting	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		Severe erosion	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		Cracking	▲	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		Impending overtopping	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP	
		"Rock" noise	X	X	X	X	X	X	X	X	●	X	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP
		Fire	X	X	X	X	X	X	X	X	●	X	X	X	X	X	X	X	X	●	X	X	X	X	▲	X	NAP
Practicality	Coast	Headwater end tailwater	●	▲	▲	▲	X	X	X	X	●	X	X	X	X	X	X	●	X	X	X	X	▲	X	X	NAP	
		Initial cost	M	H	H	H	H	M	M	L	H	H	L	L	L	L	L	H	L	M	M	L	L	L	L	NAP	
		Operating cost	M	H	H	H	H	M	M	H	M	H	L	L	L	L	L	H	M	M	M	M	M	M	M	NAP	
		Date collection	H	H	H	H	H	L	L	L	L	L	L	L	L	L	L	L	M	M	M	M	M	M	M	NAP	
		Data analysis	M	M	M	M	M	H	L	L	M	L	L	L	L	L	L	M	M	M	M	M	M	M	M	NAP	
	Personnel	Number of people required	L	L	L	L	L	L	L	L	H	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	NAP
		Average training level	M	H	H	H	H	H	H	L	L	L	L	L	L	L	L	L	L	M	L	L	L	L	L	L	NAP
		Reliability (longevity)	H	H	H	H	H	M	M	H	H	H	H	H	H	H	H	H	H	H	M	M	M	M	M	M	NAP
		All-weather capability	L	L	L	L	L	M	M	H	M	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	NAP
		Development required	L	L	L	L	L	M	M	L	L	L	L	L	L	L	L	L	L	L	M	L	L	L	L	L	NAP
Success probability	Quantity volumes	●	X	X	X	X	X	X	X	●	X	X	X	X	X	X	X	X	X	M	L	L	L	L	L	NAP	
	To assess stability	H	L	L	L	L	L	L	L	0	0	0	0	0	0	0	0	0	0	M	L	L	L	L	L	L	
	Meet overall aims	H	O	O	O	O	O	O	O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

KEY

NAP Not applicable or unknown

● Suitable

▲ Possibly suitable

X Not suitable

H High

M Medium

L Low

0 None

KEY

NAP Not applicable or unknown

● Suitable

▲ Possibly suitable

X Not suitable

H High

M Medium

L Low to none

O None

FIGURE 1.—Matrix of monitoring methods—Continued.

Roseburg, OR, was selected as the primary site. Two stable coal refuse sites were selected for later evaluation.

The landslide was monitored with 22 targets situated on the actively moving surface and 13 targets acting as control points off the active area. All targets and control points were surveyed to first-order accuracy, and the coordinate system was determined with a least-squares computation. The site was monitored once a month from February to May 1976 by comparing aerially derived coordinates for each target to actual second-order (± 0.02 ft) ground surveys. Using a higher order accuracy, 20% of the aerial system's coordinates were within ± 0.05 ft of the coordinates determined by ground surveys, 80% of the total readings were within ± 0.10 ft, and 99% of the readings were within ± 0.25 ft.

Data from the Roseburg landslide indicated that aerial monitoring could work on active, steep terrain; therefore, two coal refuse embankments in West Virginia were selected as the next evaluation sites.

The Wharton refuse embankment is 500 ft high with a 1,500-ft crest length and covers approximately 50 acres. It was built between 1956 and 1976 with aerial-tram-deposited material and contained an upstream pond. Thirty-six targets were installed and ground-surveyed on the embankment and at seven control points. During monitoring, 20 targets were destroyed by mine activity. Ground surveys were conducted at the beginning and end of the monitoring period.

The Stirrat refuse embankment is 490 ft high with a 1,700-ft crest length and covers approximately 40 acres. It forms an impoundment with 250 ft of freeboard and was constructed via aerial tram between 1945 and 1970. Since 1970, mixed coal waste and fine slurry have been hydraulically discharged behind the dam. Thirteen targets were installed on the embankment and at four control points. Stirrat was used as a regular inspection prototype. Ground surveys of targets were conducted only at the beginning and end of the monitoring period to determine if any had moved during the 6-month

period of monitoring, July through December 1976.

Equipment and Instrumentation

The aerial monitoring technique incorporated the least-squares computation for calculating ground coordinates of targets on an embankment from measured coordinates of their images on three overlapping aerial photographs. The flight of the fixed-wing, low-altitude aircraft used vertical and, for more accuracy, convergent photographs (fig. 2), as opposed to the more conventional, vertical only, 60% overlap photographs.

Typical flight lines were developed to optimize mapping accuracy of coal refuse sites (fig. 3). Ground targets 11 in. in diameter, painted nonreflecting white and with an anchor pipe, afforded high visibility (fig. 4). However, these targets would be unsuitable in winter snows.

Other equipment used during the study included--

1. Wild RC-8,⁴ 6-in focal length mapping camera with a 9- by 9-in format size.
2. Monocomparator which measured X and Y image coordinates to the nearest 1×10^{-6} m.
3. Optical stereoscope to gather qualitative information from the aerial photographs; for example, cracks, bulges, slumps, erosion, and seeps.
4. Fixed-wing aircraft.
5. Minicomputer to reduce data points to coordinates.
6. Kodak Double-X Aerographic 2405 (estar base) black and white (B+W) film.
7. Kodak Aerochrome Infrared 2443 (estar base) color infrared (CIR) film.

Results

The data and results of this aerial monitoring effort are described in more detail in the full report (8); however, the significant factors that must be con-

⁴Reference to specific products does not imply endorsement by the Bureau of Mines.

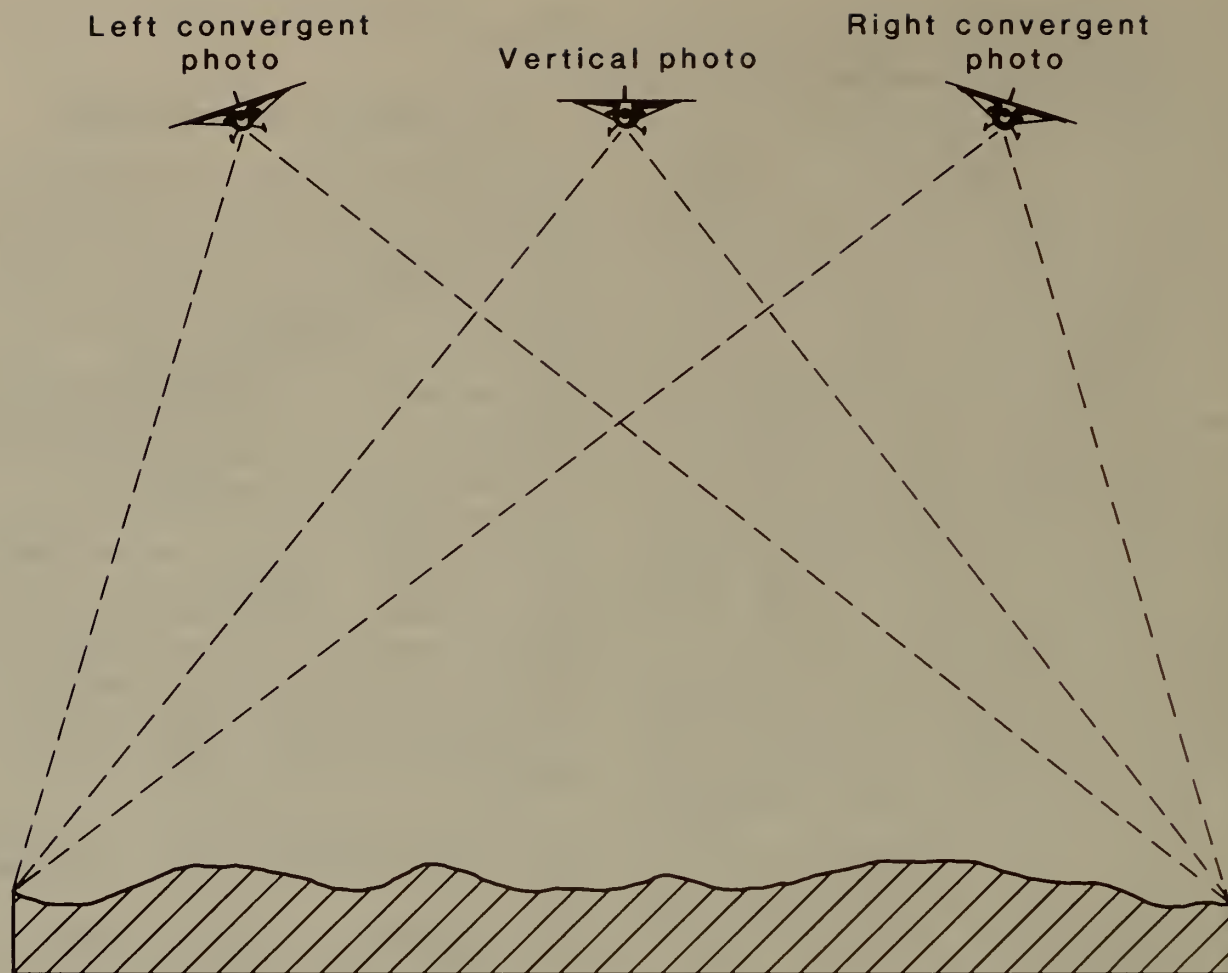


FIGURE 2.—Convergent aerial flight scheme.

sidered when using aerial monitoring of waste embankments are summarized as follows:

1. Depending on the area to be monitored, the camera, and the flying height, the average scale of the aerial photographs upon which all photogrammetric measurements were based was 1:4500 to 1:5400. The maximum area encompassed by a flying height of 2,700 ft above the mean terrain would be 4,000 by 4,000 ft.

2. The accuracy of producing topographic contours from aerial measurements was 1:500 to 1:2000 of the flying height.

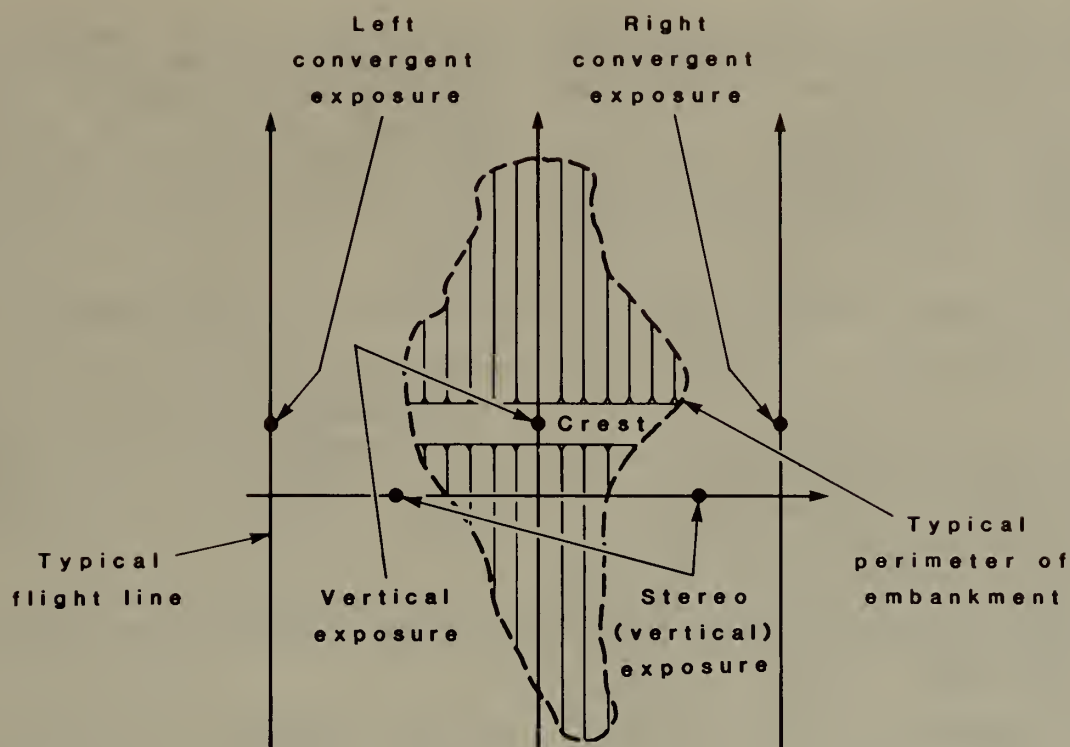
3. B+W film needs no special storage consideration and is conducive to reproduction. However, because of the eye's limited response to varying tones of gray, it is difficult to differentiate variations in, for example, vegetation and moisture.

4. CIR film is sensitive to temperature variations and humidity and must be kept in a refrigerator or freezer with adequate thawing out time prior to use to avoid moisture condensation during exposure. The color resolution also deteriorates in poor weather, and the longer shutter speeds needed for low-sun-angle shots in the fall and winter cause blurred targets under magnification.

5. Neither B+W nor CIR film proved clearly superior to the other for either quantitative or qualitative interpretation.

6. The theoretical accuracy of 1:35,000 for convergent photogrammetry was not achieved.

7. The photogrammetric method of monitoring produces a permanent, visual, and, most importantly, objective record of the site.



LEGEND

- Direction of flight lines
- Aerial photograph taken at this location

FIGURE 3.—Typical exposure layout.

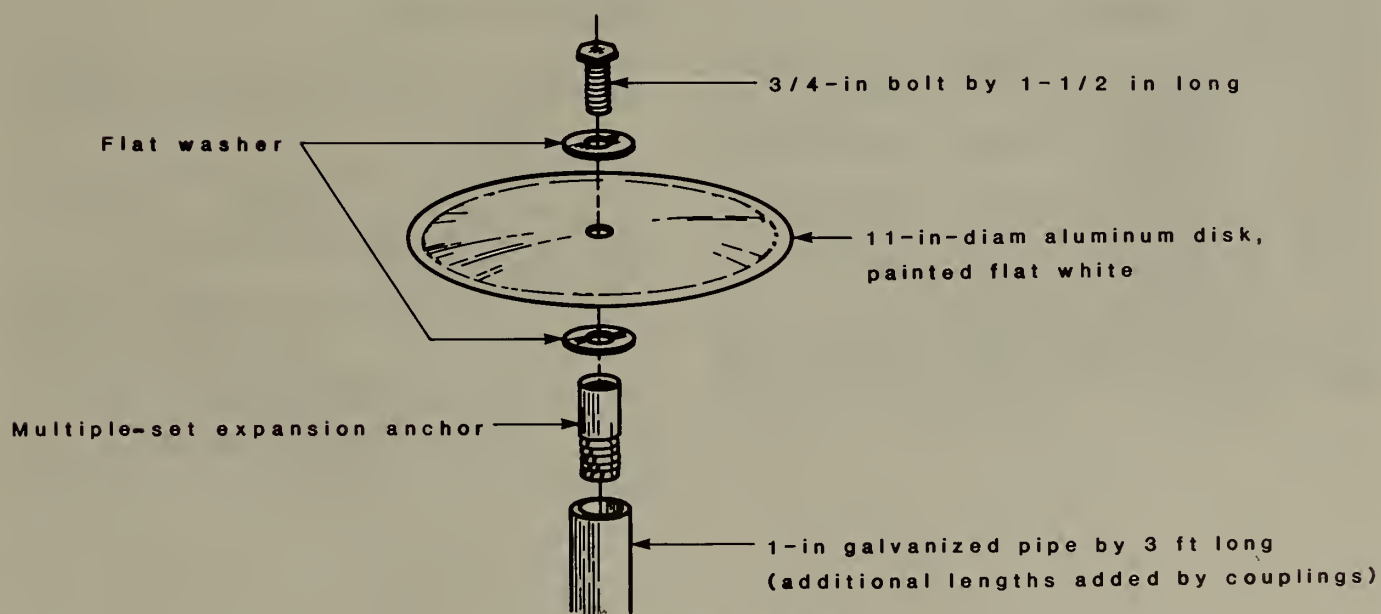


FIGURE 4.—Ground target detail.

8. The cost of aerial monitoring ranged from 40% of conventional ground surveys on the Oregon landslide to 15% on the two coal refuse sites.

9. Aerial monitoring costs were 175% to 300% more than costs of the current Mine Safety and Health Administration (MSHA) routine (table 1).

10. Total costs for aerially monitoring a coal waste site would vary greatly depending on the number of sites to be monitored, the number of flights, the area to be covered, the target installation, and the ground survey (table 2).

TABLE 1. - Comparison of possible inspection programs (based on 1975-76 costs)

Program	Staff capability, embankments per month (3-member staff)	Average cost per embankment
A Current inspection methods ¹	60- 90	\$150-\$200
B Conventional ground survey methods.....	3- 5	2,000-3,500
C Rapid monitoring system ²	90-130	350- 500
D Combination, current methods and rapid monitoring system.....	70-100	230- 330

¹Based on data from MESA District 4 (now MSHA).

²Using 1 film type.

Program A remarks:

1. Inspections are qualitative only.
2. Written descriptions of conditions are recorded on standard forms.
3. Possible unsafe conditions may be overlooked or misinterpreted because of lack of physical measurements or lack of experience of the inspector.
4. Economical.

Program B remarks:

1. Capable of detecting and monitoring movement.
2. Capable of mapping and determining quantities.
3. Provides written record.
4. Time consuming.
5. Labor intensive.
6. Costly.

Program C remarks:

1. Capable of detecting and monitoring movement.
2. Capable of mapping and determining quantities.
3. Provides permanent, visual record.
4. Provides qualitative data.
5. Economical in comparison with conventional ground survey.
6. Enables experienced people to view (via photos) many embankments per month.

Program D remarks:

1. Capable of monitoring more embankments than current inspection methods.
2. Provides qualitative information on all embankments and quantitative information on selected embankments.
3. Inspections would allow for better allocation of field inspection resources for suspect embankments.
4. Method would be more economical than rapid monitoring alone.

TABLE 2. - Initial costs of monitoring
(based on 1975-76 costs)

Rapid monitoring system:	
Airplane.....	\$55,000
Aerial mapping camera.....	75,000
Monocomparator.....	30,000
Total cost.....	<u>160,000</u>
Conventional ground survey:	
Theodolites (2), at \$5,000	
each.....	10,000
Engineer's level.....	1,500
Electronic distance-measuring	
equipment.....	8,000
Miscellaneous equipment.....	3,500
Total cost.....	<u>23,000</u>

Certain disadvantages of the aerial monitoring technique became evident as the project proceeded:

1. To achieve the accuracy desired, convergent photography was used.

2. This type of photography required four flybys per site (three for convergent and one for stereo), and the accuracy was dependent on the capability of the aircraft to tilt at a specified angle twice over each site.

3. Movement on the embankment, indicating instability, could only be detected at the target itself.

4. The targets, especially those placed on the embankment, were highly susceptible to damage and to surface movement due to construction activity, vandalism, or looseness of the embankment material.

5. Aerial monitoring is also highly dependent on weather.

6. Haze, cloud cover, snow, low sun angles, and other problems decrease accuracy and hamper or preclude the ability to take photos.

Recommendations

As described in the full report (8), the following procedures and conditions

are recommended in order to obtain optimum results:

1. More reliable results can be achieved if the camera is fixed on a rotating mount within the aircraft than by attempting to tilt the aircraft to obtain convergent angles.

2. Ground targets should be a minimum of 1:2000 of the flying height above the mean elevation of the embankment to optimize monocomparator results.

3. An accounting system to replace lost or damaged targets must be included in a monitoring scheme of this type.

4. Control points should be surveyed after the flight lines are determined so that they can be located as near the four corners of the photos as possible.

5. To obtain the best target readings, the aircraft should fly directly toward the face of the slope; that is, the flight lines should be perpendicular to the crest of the embankment.

6. To obtain the best results for stereophotography, the flight lines should be parallel to the crest of the embankment.

STUDY 2

Study 2 of the Bureau's aerial photogrammetric investigations began in 1979, monitoring 15 coal waste sites once a month for 10 months through seasonal changes (6). This contract investigation was performed by Chicago Aerial Survey. The method for taking photos and the technique for obtaining elevations of the targeted site were different from those of the first aerial study. Specifically, this contract was intended to determine the best procedure, the level of accuracy, and the costs of using aerial photogrammetry to monitor coal refuse disposal sites in comparison with current MSHA inspection practices.

Description of Work

In this study, large-scale, low-altitude, aerial photos were analyzed for vertical elevations through an analytical stereoplotter. In this technique, a stereoplotter operator benchmarks known elevation coordinates on control targets surrounding the coal refuse site and thus can determine the elevation of any other point on successive orthophotos. This technique is not dependent upon targets being placed on the investigation site, as was the case in the first study. Instead, control targets off the sites in question were ground-surveyed at the beginning of the monitoring period for reference X and Y coordinates and elevations. Use of such reference points out of the movement area was a distinct advantage because they were not affected by any movement on the target area or by other disturbances such as construction activity.

Fifteen coal waste sites in West Virginia and Kentucky were monitored once a month for 10 months using B+W aerial photography and four separate times using CIR. Four field inspections of the sites, using procedures similar to MSHA's inspection procedures, were made. The inspections familiarized the observers with the sites, enabling them to compare the results of the stereo and photogrammetric observations with ground observations. The ground inspections were conducted on a seasonal basis, as was the CIR photography. This format allowed a determination of the effects of seasonal changes and the correlation of aerial to ground observations.

Low-altitude flights were conducted over each site to obtain the aerial photos. Because the refuse piles varied in size, various scales of photography were implemented to encompass each site with the surrounding ground control targets in a single stereoscopic model. The scales ranged from 1:5400 (1 in = 450 ft) to 1:9000 (1 in = 750 ft), using flight altitudes of 2,700 to 4,500 ft above the average terrain elevation. This scaling restriction limits the dimensions of the site to be monitored to 1,620 by 3,150 ft

at 1:5400 and to 2,700 by 5,250 ft at 1:9000. (The ground control targets outside the refuse pile area must be included in the dimensions.)

From the aerial photographs, orthophotographs were produced. These are aerial photos of fixed scale in which all distortions and displacements have been corrected (camera tilt, terrain-relief displacement, etc.). The orthophotograph is then a scaled picture map on which one can directly measure distances and, when overlaid with contour information, produce elevation readings at any point. Figure 5 shows an orthophoto flight map with topographic contours overlaid. The contours were generated from compilations of the stereoscopic models.

X, Y, and Z coordinates were read off the aerial photos using an analytical stereoplotter. For this project, a grid system of 100-ft squares was optically overlain on the orthophoto, and coordinates were taken only on the cross grids for monthly comparison of movement (fig. 6).

Various configurations for displaying the produced data were attempted. One option consisted of computer listings of each grid point with values greater than 5 ft highlighted. Another method graphically displayed the displacement mesh isometrically, displaying vertical movement (fig. 7). The displacement mesh tended to exaggerate small amounts of movement. Also, it was very difficult to orient the isometric mesh with any of the photographic products (orthophotos, contact prints, etc.) to indicate at a glance where the movement was occurring on the embankment itself.

Another technique involved suppressing the line printer information and producing a computer-drawn plot consisting of circular symbols which represented vertical movement. The type of symbol displayed represented positive (upward) or negative (downward) movement. The diameter of the circles was proportional to the magnitude of the movement and was orthogonal at the same scale as the orthophoto. The movement values were printed next to the circles (fig. 8).



FIGURE 5.—Orthophoto site map with contours.

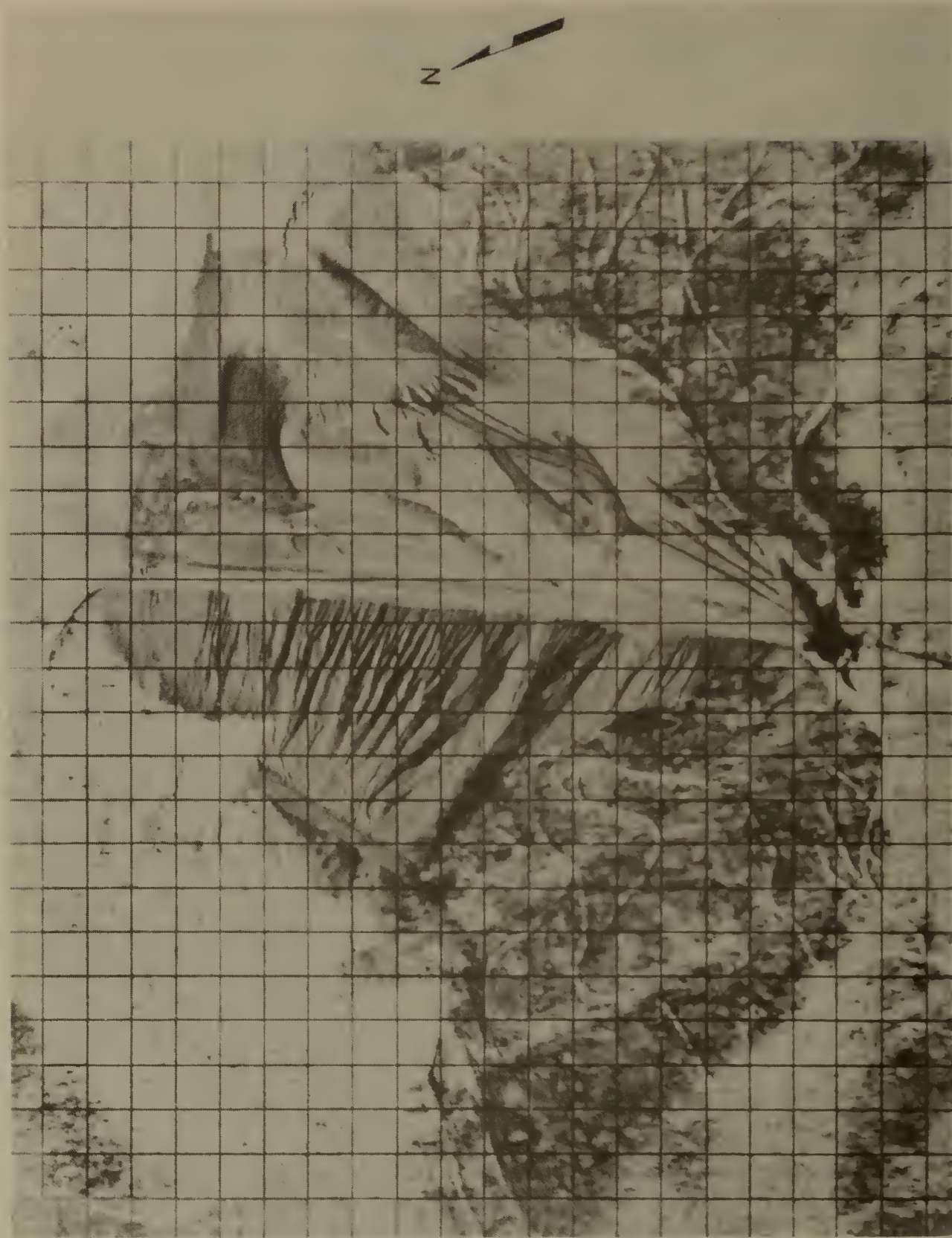


FIGURE 6. — Orthophoto with 100-ft grid.

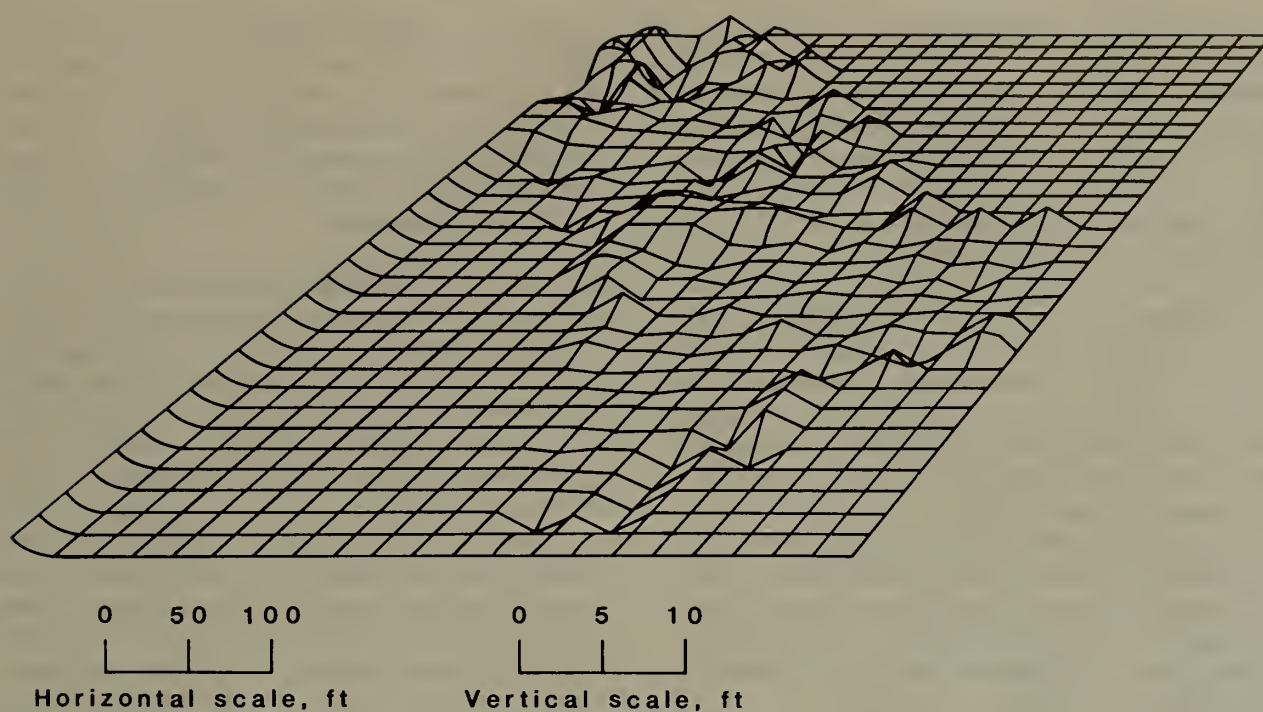


FIGURE 7.—Isometric displacement mesh.

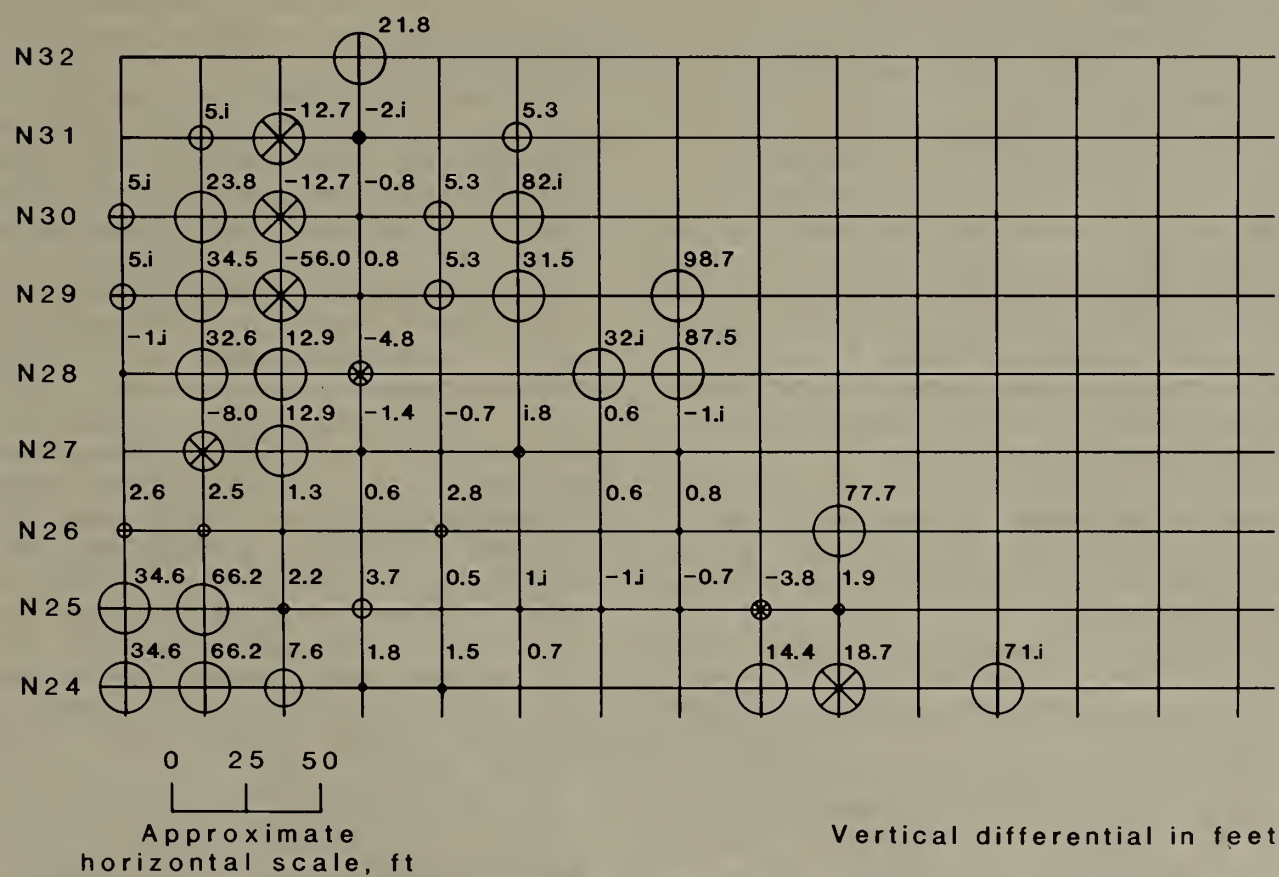


FIGURE 8.—Enlarged view of displacement vector plot.

Results

A more detailed discussion of the investigation, as well as complete data and results, may be found in the full report (6). However, the following observations were considered significant factors to this type of monitoring:

1. Sites of greater dimensions than that described would require either higher altitude photography or additional models. Higher altitude photography would lose resolution of ground features, decreasing the accuracy of the system.

2. Aerotriangulation, necessary to combine the coordinate systems of separate models into one model, introduces deviations in horizontal positions, which are extremely difficult to maintain or reconstruct in precisely the same way month after month.

3. Useful aerial photography was difficult to acquire on a monthly basis, since the area (eastern Kentucky and southwestern West Virginia) has below-average weather conditions for year-round flying, and acceptable sun angles (30° or higher above the horizon) are at best available for 5 h daily (9:30 a.m. to 2:30 p.m.) in June, dropping to 2 h (11:00 a.m. to 1:00 p.m.) in December.

4. Because of the great differences in high and low elevations on the piles and because of the normally steep slope on the downhill side, low sun angle causes unusually long and very black shadows. Crevassed or eroded areas filled with deep, black shadows make precision elevation readings nearly impossible to acquire in any stereoplotter.

5. Sites situated on the northern slopes of hillsides or mountains are totally in shadow during the winter months. This reduces photo definition by lowering image contrast.

6. Snowfall immediately prior to an aerial survey made it necessary to expose and paint some of the control targets black and white.

7. Forward overlap of 90% in the photography ensured the least amount of flying by helping to maintain complete stereo coverage.

8. A flight altitude of 1,800 ft above the mean terrain will produce optimal photography at an average scale of 1 in = 300 ft and expected spot elevation readings as precise as ± 0.15 ft, using a stereoplotter with a C-factor rating of 3,000 or greater.

9. Vegetation can be a serious problem. By the end of the summer, identification of field control points was extremely difficult, and even impossible at some of the sites, because the vegetation had overgrown the targets. Also affected were photo identification features used as control points, such as bases of utility poles. The memory function of the stereoplotter allowed the operator to eliminate sending supplemental field crews to the sites. Auxiliary control points were derived from the stereo model using points visible despite the vegetation. These points were then used to control successive stereo setups in the following months.

10. Erosion is easily seen on aerial photos, and its severity is also generally apparent. However, flattened vegetation can give an erroneous impression of serious erosion.

11. Tension cracks are generally not apparent in the photos. Cracks are sometimes visible when enhanced by erosion, deposits left from condensation of volatiles, or scarps. Scarps having more than 3 in of vertical displacement are visible on barren piles. The slumps associated with scarps are generally visible on the photos whether or not vegetation is present.

12. Using enlargements, seepage can be seen on barren piles as darker areas on the refuse. On vegetated piles, seepage is sometimes hidden by the vegetation. In other instances, seepage may be indicated by the vegetation having been washed away or by abundant growth.

13. Aerial photography is an excellent method for monitoring diversion ditch systems and water impoundments because an entire system can be viewed simultaneously.

14. Actual lift heights cannot be determined from photos alone. This can cause problems because MSHA requires that

refuse piles be constructed in compacted layers that do not exceed 2 ft in thickness, unless otherwise approved.

15. Equipment tracks observed in the photos on spread refuse can indicate that some compaction has taken place, although the actual degree of compaction cannot be determined.

16. Stereophoto analysis can be used to detect changes in slope; however, the angle of the slope is not obtainable from the photos alone.

17. CIR photography can, at times, provide more information than B+W prints. Iron staining appears as a greenish hue in well-exposed CIR photographs. The CIR also has better resolution under high magnification. Seasonal variation in conditions, particularly vegetation and snow, affect visibility of features, sometimes hiding them but sometimes highlighting them.

18. Photogrammetry (fig. 9) can be used to answer many of the questions

on the MSHA report form. The photogrammetric system used in study 2 is best for locating surface movements involving large areas because a 100-ft grid can easily miss movement occurring in areas between intersection points.

19. Orthophotos with contours can be used to determine slope, initially from the contours and later by adding changes in elevation from the computer plots.

20. Deposition is visible on the orthophotos.

21. Air photo analysis and photogrammetry do not completely answer all of the questions on the MSHA inspection form.

The advantages and disadvantages of using aerial photointerpretation in monitoring coal waste sites are listed on the next page. Table 3 tabulates cost estimates for aerial monitoring of coal waste sites as compared with MSHA inspection techniques.

TABLE 3. - Inspection costs per site (based on 1980 costs)

	1 site			2 sites			10+ sites		
	Labor	Direct	Total	Labor	Direct	Total	Labor	Direct	Total
PHOTOGRAMMETRIC METHOD									
Ground control targeting and surveying ¹	1,600	400	2,000	1,600	400	2,000	1,600	400	2,000
Target maintenance ²	25	0	25	25	0	25	25	0	25
Photographic flights using black and white film.....	80	140	220	60	110	170	50	100	150
Color infrared film in addition to black and white (assumes a dual-camera aircraft or interchangeable film magazines).....	0	10	10	0	8	8	0	8	8
Photo lab.....	17	23	40	16	22	38	15	22	37
Photogrammetry contours (orthophotos).....	80	120	200	80	120	200	80	120	200
Data processing (including volumes).....	20	25	45	20	25	45	20	25	45
Overhead.....	40	0	40	40	0	40	40	0	45
Aerial photo interpretation (by MSHA), 2 h.....	46	0	46	46	0	46	46	0	46
Total, recurring costs only.....	308	318	626	287	285	572	276	275	551
GROUND INSPECTION METHOD									
MSHA site inspection.....	450	20	470	450	20	470	450	20	450

¹Survey costs represent a 1-time expense of \$2,000 per site, which will not increase or change as monitoring time is extended.

²Average maintenance costs per monitoring flight (variable). Locations with light or no snow require little or no target maintenance during winter months. Heavy brush must be cut during summer or autumn months.

Advantages and Disadvantages of Using Aerial Photointerpretation
in Monitoring Coal Waste Sites

Advantages

Rapid return of interpretable data.

Results are "time-frozen" - the aerial film preserves a record of the site at the time of flying. The film can be re-set in a stereoplotter at any time to verify derived data relative to monitoring. This becomes more of an advantage over a period of time, when not only data from consecutive monitoring periods can be compared, but also data from monitorings months or years apart. New types of data may also be determined from earlier photography.

Aerial monitoring reduces field time.

Aerial monitoring provides the inspector, through typical stereoplotting instruments, the opportunity to measure any or every visible point on the embankment surface.

Aerial monitoring offers reliable relative measurements economically.

Minimal ground survey is required for control of the photography.

Accuracies of ground readings can be a function of the photogrammetric equipment, typically ranging from 1:2000 to 1:4000, or the aircraft altitude.

Disadvantages

Sufficient targets of photoidentifiable control points are required for use in controlling the stereo model setup; however, inaccessibility of many sites and activity on and around the sites make the targets vulnerable to disappearance and destruction.

Accuracy of elevation readings was disappointing. Accuracy problems are encountered due to lack or loss of control points, terrain slope, vegetation growth, shadows, atmospheric conditions, enforcement of readings at specific locations, or any combination of these.

The 100-ft grid readings are not sufficient to define true surface characteristics of the pile. Predefined grid intersection points present only comparison readings at these points. High and low surface points (peaks and valleys) are not well defined.

The selection of stereo instruments is restricted to those with a large range of elevation-measuring capability because of the great differences in pile elevation. Instruments should be equipped with 3-axis digital readout to facilitate numerical model setup and stereo observation.

The cost is greater than for on-site visits; see table 3.



FIGURE 9.—Qualitative features distinguishable on an aerial photo.

Recommendations

Based on the results from study 2 of the aerial monitoring investigation, the following recommendations are made:

1. Monthly aerial analysis is not justified; the minimal amounts of surface movement or change detectable from month to month suggest it is necessary to review surface conditions periodically, but semiannual aerial inspections seem to provide sufficient sampling of most stable sites. Inactive sites would generally require less frequent aerial monitoring.

2. Flights should occur at the lowest possible, nonhazardous altitude in order to take photographs that include one individual site in a single flight line.

3. Atmospheric conditions such as haze and cloud cover should be closely watched because they can greatly influence the photo resolution.

4. All targets should be placed or made visible before each flight.

5. Wherever possible, the surrounding embankment should be saturated with control targets to ensure adequate reference point survival through the monitoring period.

6. Trigonometric levels are sufficient for determination of target elevations. Because only a relative datum is important, spot elevations from U.S. Geological Survey (USGS) quadrangle maps may be used to provide a vertical datum. These should be as near to the corners of the stereo model as possible.

7. Targets should be referenced by sketch and description to three physical objects to aid in accurate repositioning should panels be moved or destroyed.

8. Once horizontal and vertical controls are determined for model setup (orthophoto, stereophoto analysis), field personnel are not required for aerial procedures except for maintenance of the targets.

9. Targets should be durable and securely anchored and may be of any shape easily recognizable in the aerial photographs.

10. Consistent reconstruction of the original stereo model setup is the most critical operation in the photogrammetric procedures. It is essential that control points be sufficient in number and clearly visible at all times.

11. Targets that were not survey-coordinated during field operations should be used as auxiliary control points.

12. It is possible to use premarked auxiliary control points. These are points created by drilling tiny holes in the photo emulsion using a point marking and transfer device. These points can be transferred accurately from one month's flying to the next, as long as the images are compatible.

13. Profiles should be determined transversely and perpendicularly to the crest of the embankments. Elevation points for these profiles should be taken at a maximum distance of 25 ft, using the "most favorable location for reading" technique. A minimum of three parallel transverse profiles should be determined for each embankment. Large embankments should have five of these profiles. Information derived from the profiles includes determination of slope of the embankment face, determination of actual buildup on active piles, verification of trends noticed in examination of the basic profiles, and slippage at the crest and buildup at the base of piles.

Both studies 1 and 2 were based on elevations determined at specific locations on the surface of an embankment. Because of the unreliability of elevation readings, enforcing point-reading locations does not appear to be effective.

A more effective system of surface definition would allow point selection by visual means, using a "most favorable location for reading" technique. That is, a stereoplotter operator reads points that he or she can see well to ensure precision and reliability of point readings. The operator would also be able to read an indefinite number of points, reading high and low spots and other points on the surface not farther apart than 25 ft. Figure 10 compares the

fixed-grid method with the "most favorable location" technique. Details of

this system may be found in the study 2 report (6).

REMOTE DATA TRANSMISSION

PHASE 1. - IN SITU INSTRUMENTATION WITH REMOTE DATA COLLECTION BY TELEPHONE

In phase 1, a contract was awarded to Shannon & Wilson, Inc. (4), to develop and demonstrate an instrumentation system that could be wired to a remote data collection station for the purpose of centrally monitoring the stability and seepage of one or more coal waste impoundments. Costs of system installation and long-term monitoring were also determined. Specifically, the instrumentation system was designed to remotely monitor horizontal and vertical deformation, pore-water pressure changes, pond-water levels, seepage through the embankment, and environmental factors such as rainfall, temperature, and barometric pressure.

Description of Work

Factors considered in site selection were--

1. Location in a populated area with high precipitation rates.
2. Some certainty of measuring parameter changes such as deformation, water pressure, and fluid levels.
3. Height of structure in the range of 100 to 200 ft.
4. Cooperation of mine owner and permission to use the waste impoundment.
5. Electrical power and telephone available close to site.

These particular factors were selected on the basis of the project requirements, the cost estimates made in the proposal,

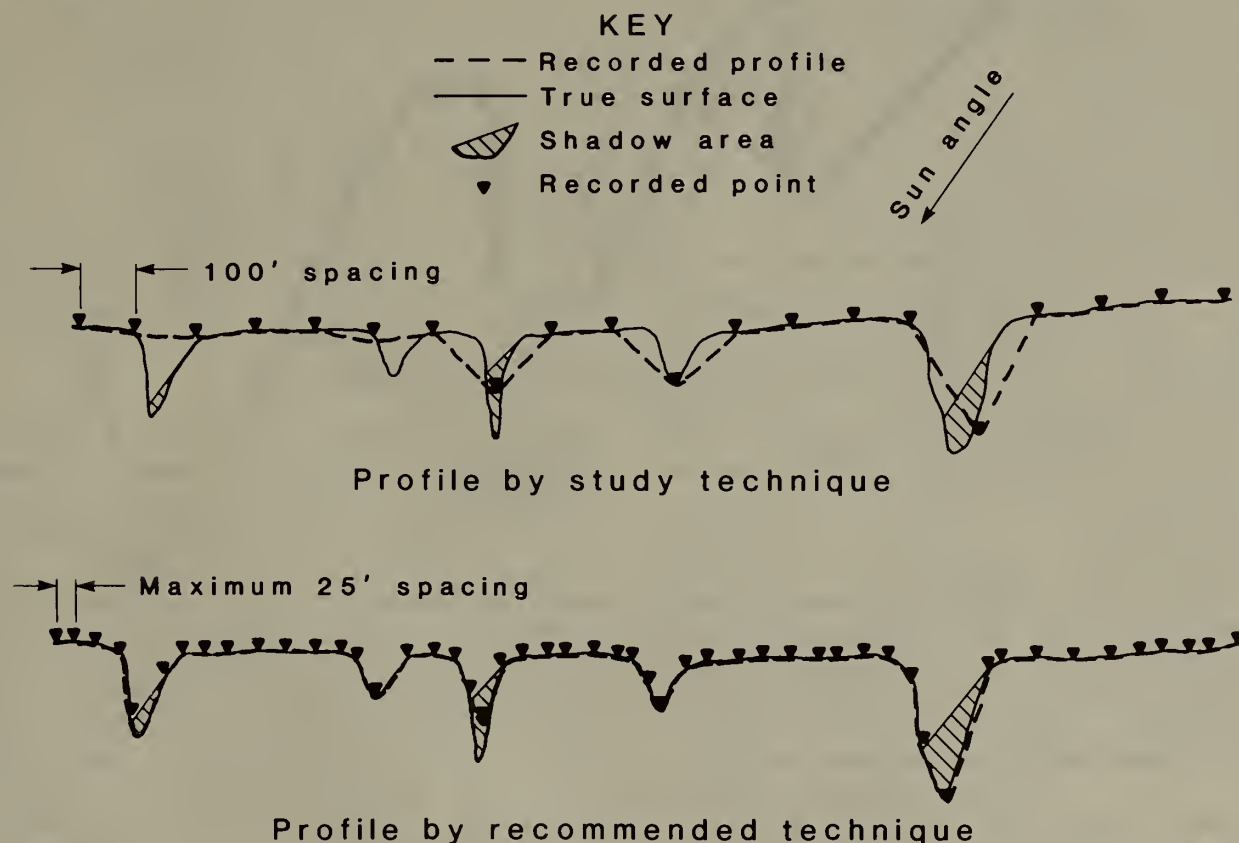


FIGURE 10.—Typical surface profile comparing 100-ft grid to favorable point readings.

and the ability to best demonstrate the full capabilities of a remote monitoring system.

The site selected was the Lower Big Branch Impoundment at Montcoal, WV, operated by ARMC Material Resources. It is a cross-valley coarse refuse embankment impounding about 5 acres of fine coal refuse slurry pumped 1 mile from the No. 7 Mine preparation plant (fig. 11). Its height was about 190 ft (1,120-ft elevation) and will eventually be raised to 1,175-ft elevation. The Lower Big Branch Creek has been relocated to the south side of the impoundment and flows into March Fork Creek, which occupies the valley directly below the embankment. The topography of the area is relatively steep with heavily wooded hillsides. The

local geology is composed of interbedded layers of sandstone, shale, and coal.

Equipment and Instrumentation

Available instrumentation was evaluated and selected for its capability of monitoring various parameters, its suitability to long-term measurements, and whether or not it was an electrical sensor amenable to automatic remote monitoring. A complete remote instrumentation system for monitoring the stability of a waste embankment was designed (fig. 12). Final instrumentation installed in the embankment included 7 vibrating wire piezometers, 2 resistance piezometers, 3 biaxial tiltmeters (2 sensors each), 3 multiple-position borehole extensometers



FIGURE 11.—Lower Big Branch Impoundment site plan.

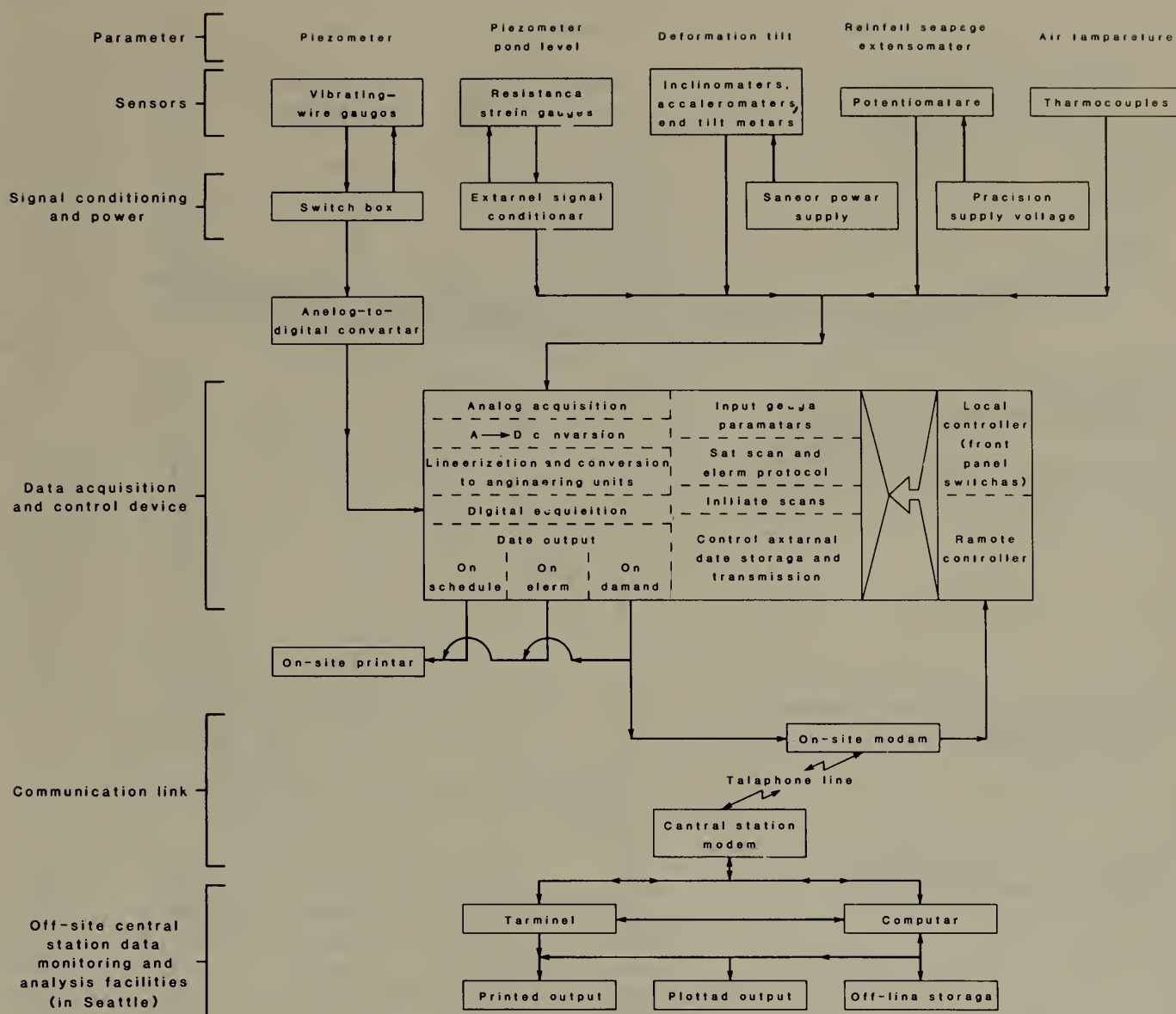


FIGURE 12.—Block diagram of remote instrumentation system.

(1 with 4 sensors, 2 with 2 sensors each), 1 uniaxial in-place inclinometer with 8 sensors, 1 fluid-level-monitoring device to measure seepage at the weir, 1 barometer, 1 rain monitor, and 2 thermocouples, for a total of 21 instruments and 37 sensors (table 4, figures 13-14). These instruments (figs. 15-17) were connected via two junction boxes (fig. 18) and buried cable to the automatic data acquisition system (DAS) located in a trailer at the test site. The DAS consisted of power conditioning equipment, a signal conditioning unit,

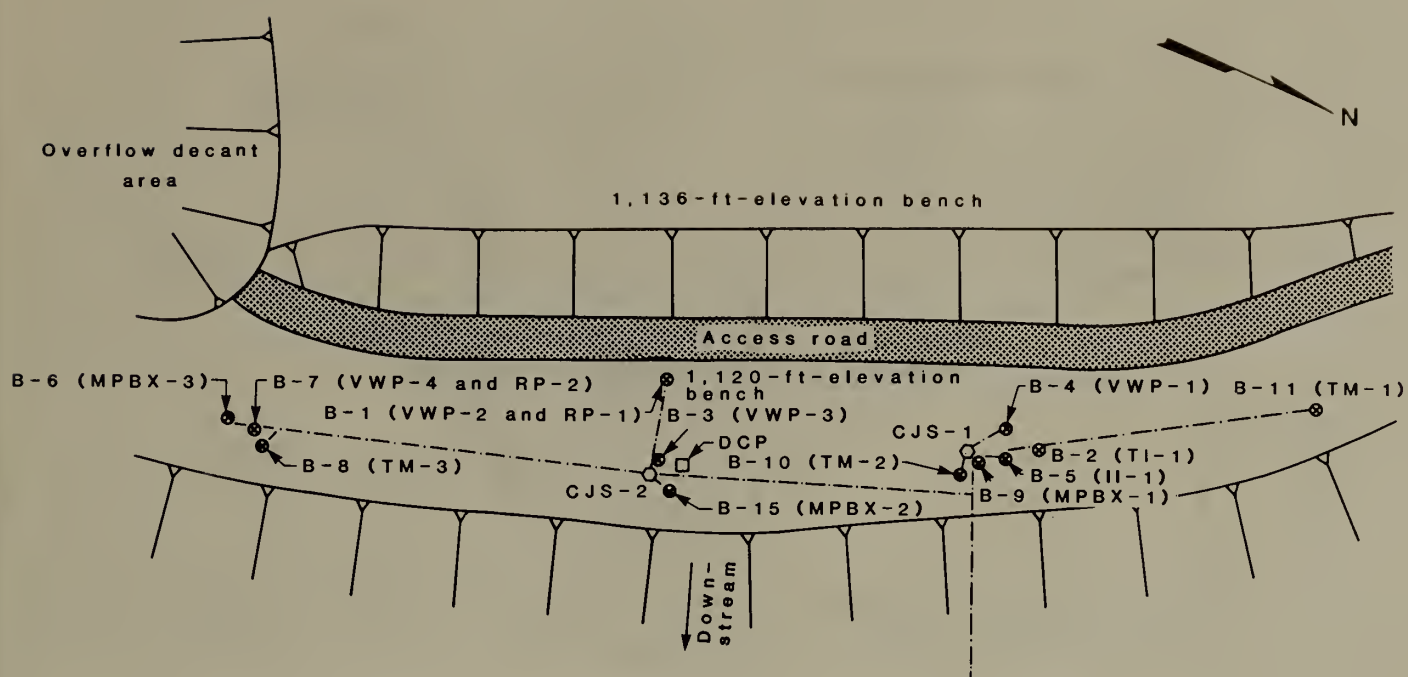
and an Acurex Autodata 9 data logger connected to the telephone. Data were recorded automatically at the site on paper tape and on request at the contractor's office via the telephone. The pond level sensor initially installed in the upstream impoundment was destroyed early in the program when it was covered with coarse refuse as the embankment was being raised. Other instruments and data acquisition systems are discussed and compared in the report (4).

The goals of the field monitoring were to collect sufficient data to determine

TABLE 4. - List of sensors and locations

Sensor, manufacturer, and model number	Sensor No.	Serial No.	Borehole location	Elevation, ft	Depth, ft
Extensometer, multiple-position borehole, Slope Indicator, model 51891.	MPBX-1(1)	L.P.1	B-9	978.8	140.7
	MPBX-1(2)	L.P.3	B-9	1,010.5	109.0
	MPBX-1(3)	L.P.4	B-9	1,044.9	74.6
	MPBX-1(4)	L.P.5	B-9	1,098.5	21.0
	MPBX-2(1)	L.P.7	B-15	942.9	176.3
	MPBX-2(2)	L.P.6	B-15	1,042.6	76.6
	MPBX-3(1)	L.P.10	B-6	946.7	171.5
	MPBX-3(2)	L.P.8	B-6	1,043.7	74.5
Fluid-level-monitoring device, Leupold & Stevens, model A-71.	Weir	98172	(¹)	NAP	NAP
Inclinometer, uniaxial in place, Slope Indicator, model P/N50432.	II-1	021	B-5	985.1	134.2
	II-2	020	B-5	993.1	126.2
	II-3	022	B-5	1,001.1	112.2
	II-4	019	B-5	1,009.1	110.2
	II-5	017	B-5	1,017.1	102.2
	II-6	016	B-5	1,025.1	94.2
	II-7	018	B-5	1,033.1	86.2
	II-8	015	B-5	1,041.1	78.2
Piezometer, electrical resistance, Slope Indicator, model P/N 56442.	RP-1	41107	B-1	942.7	176.9
	RP-2	41109	B-7	1,013.8	105.2
	Pond level sensor	41108	(¹)	1,105	NAP
Piezometer, vibrating wire, Irad Gage Co., model PW-100.	VWP-1	14-2	B-4	1,015.2	104.6
	VWP-2	14-7	B-1	943.8	175.7
	VWP-3	14-6	B-3	1,002.7	117.0
	VWP-4	14-9	B-7	1,015.0	104.0
	VWP-5	14-3	B-12	942.8	139.0
	VWP-6	14-8	B-13	930.5	125.7
	VWP-7	14-1	B-14	920.0	73.2
Pressure transducer, Setra, model 250.	Barometer	24174	(²)	1,085	NAP
Rain monitor, Leupold & Stevens, model A-71.	NA	91871	(²)	NAP	NAP
Thermocouple, Pyrometric Service, model type "T" thermocouple.	TC-1	NA	(²)	NAP	NAP
	TC-2	NA	(²)	NAP	NAP
Tiltmeter, biaxial, Slope Indica- tor, model P/N50327-1.	TM-3(A)	NA	B-8	1,118.8	2.0
	TM-3(B)	NA	B-8	1,118.8	2.0
Tiltmeter, biaxial, Terra Technol- ogy, model 85-2032.	TM-1(A)	101	B-11	1,118.0	2.0
	TM-1(B)	101	B-11	1,118.0	2.0
	TM-2(A)	102	B-10	1,119.3	2.0
	TM-2(B)	102	B-10	1,119.3	2.0

NA Not available. NAP Not applicable. ¹See figure 11. ²At instrument trailer.



- LEGEND**
- Cable junction station (CJS)
 - ⊗ Borehole with instruments
 - MPBX Multiple-position borehole extensometer
 - VWP Vibrating-wire piezometer
 - RP Resistance piezometer
 - TM Tiltmeter
 - TI Traversing probe inclinometer
 - II In-place inclinometer
 - Buried cable
 - Data collection platform (DCP)

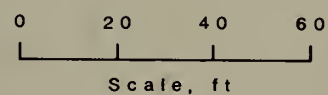
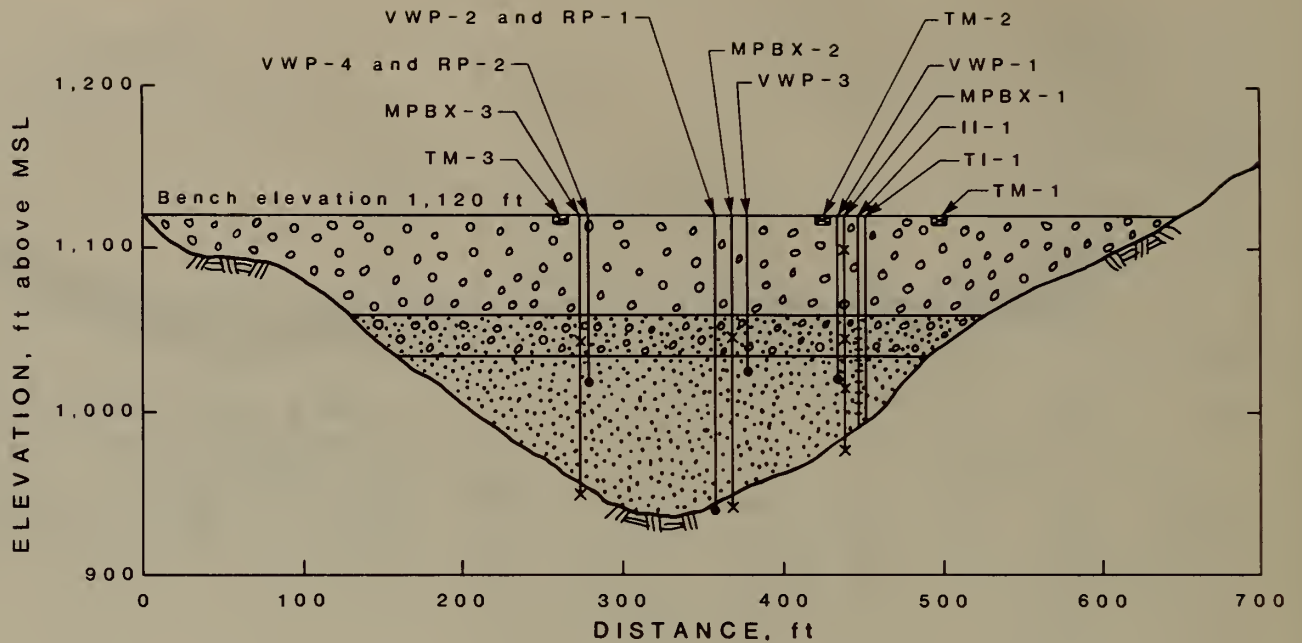


FIGURE 13.—Site instrumentation location.



LEGEND

- | | |
|--|------------------------------|
| In-place inclinometer with sensor locations (II) | Coarse coal refuse |
| Inclinometer casing for traversing probe (TI) | Fine coal refuse |
| Multiple-position borehole extensometer with anchor locations (MPBX) | Mixed coarse and fine refuse |
| Vibrating wire piezometer or resistance piezometer (VWP or RP) | Approximate top of rock |
| Tiltmeter (TM) | |

FIGURE 14.—Cross-section instrumentation location. Derived in part from 1978 D'Appolonia report entitled "Modification to Existing Coal Refuse Disposal Facility, Lower Big Branch, Montcoal Raleigh Co., WV." (3)

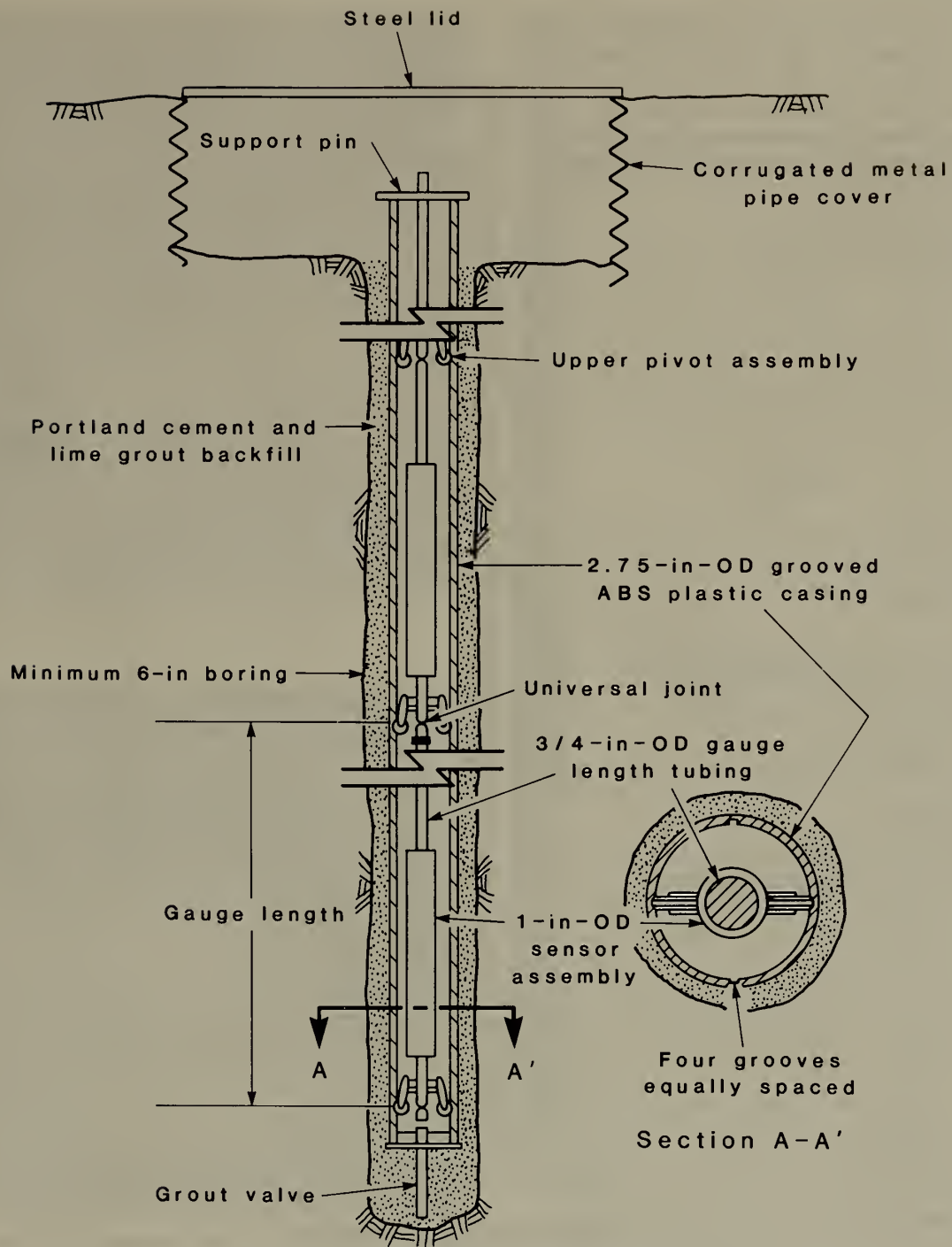


FIGURE 15.—In-place inclinometer installation.

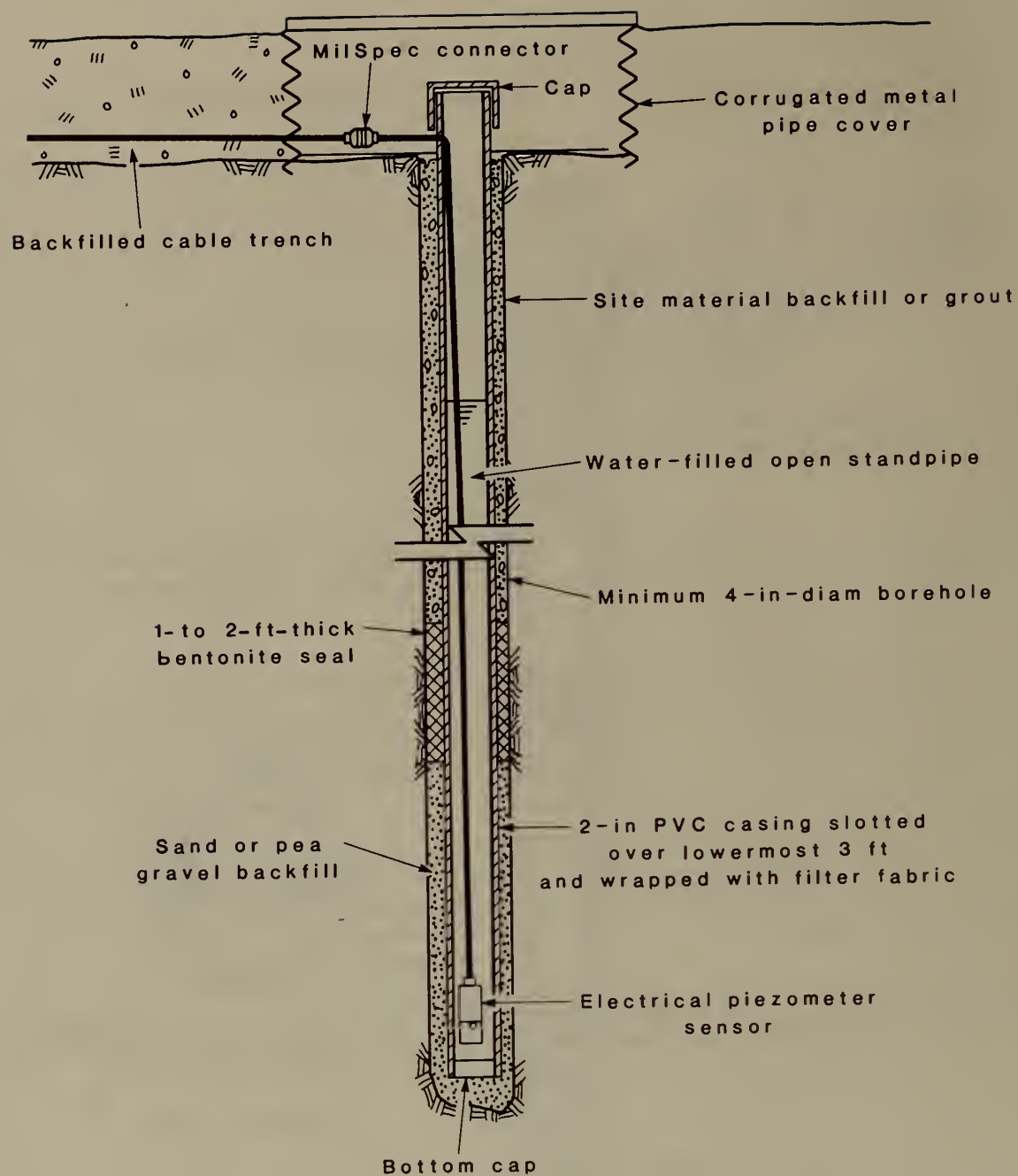


FIGURE 16.—Piezometer installation.



FIGURE 17.—Tiltmeter installation.

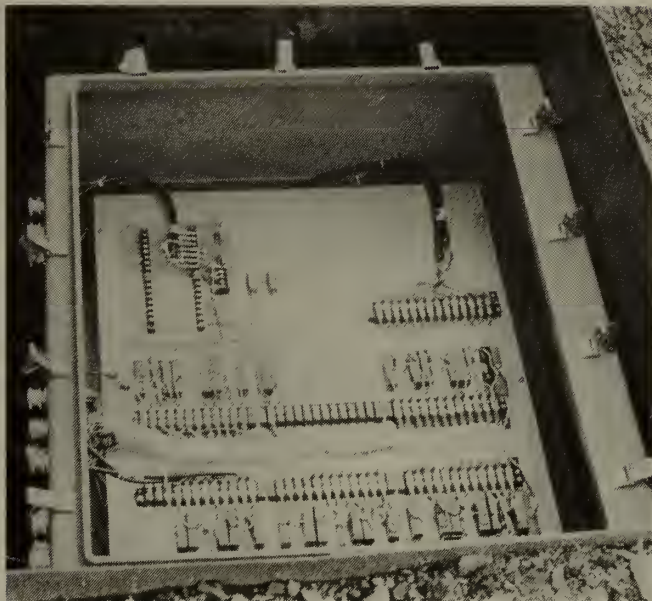


FIGURE 18.—Electrical cable junction box.

the applicability and reliability of the system, to provide typical embankment data and some site-specific data, and to provide precursory data in case of an instability developing in the embankment.

Data were to be collected at 1- or 2-day intervals. However, owing to various problems with the data logger, data had to be collected manually by calling the site to activate the instruments and take readings. Other problems included downed telephone lines, loss of the source of power from a nearby mine (a generator was substituted for a short time), damaged or nonfunctioning equipment, and site construction and maintenance activity.

The data were processed by a DEC PDP 11/34 minicomputer and plotted with programs written specifically for this particular sensor configuration.

Results

Complete data and results of this study are described in more detail in the contract report (4). Significant factors noted were--

1. Despite numerous disruptions in the monitoring process which made it difficult to obtain long-term continuous data (fig. 19), several events could be observed:

- A. Consolidation appeared to be occurring as the embankment was raised from the 1,120-ft elevation to the 1,175-ft elevation and as the pond extended several hundred feet upstream.

- B. A 1.1-in deflection occurred at an elevation of 1,043 ft in the fine refuse in the embankment, probably owing to the additional fill added to the embankment.

- C. Pore-water pressures within the embankment remained relatively constant throughout the test. The piezometer levels ranged from 15 ft above bedrock in the old portion of the embankment to about the fine-coarse coal interface at 1,035-ft elevation.

2. An approximate cost analysis for the system indicates that an automatic system is justified if the impoundment is monitored three times a week for 8 yr (table 5, figure 20). A manual system

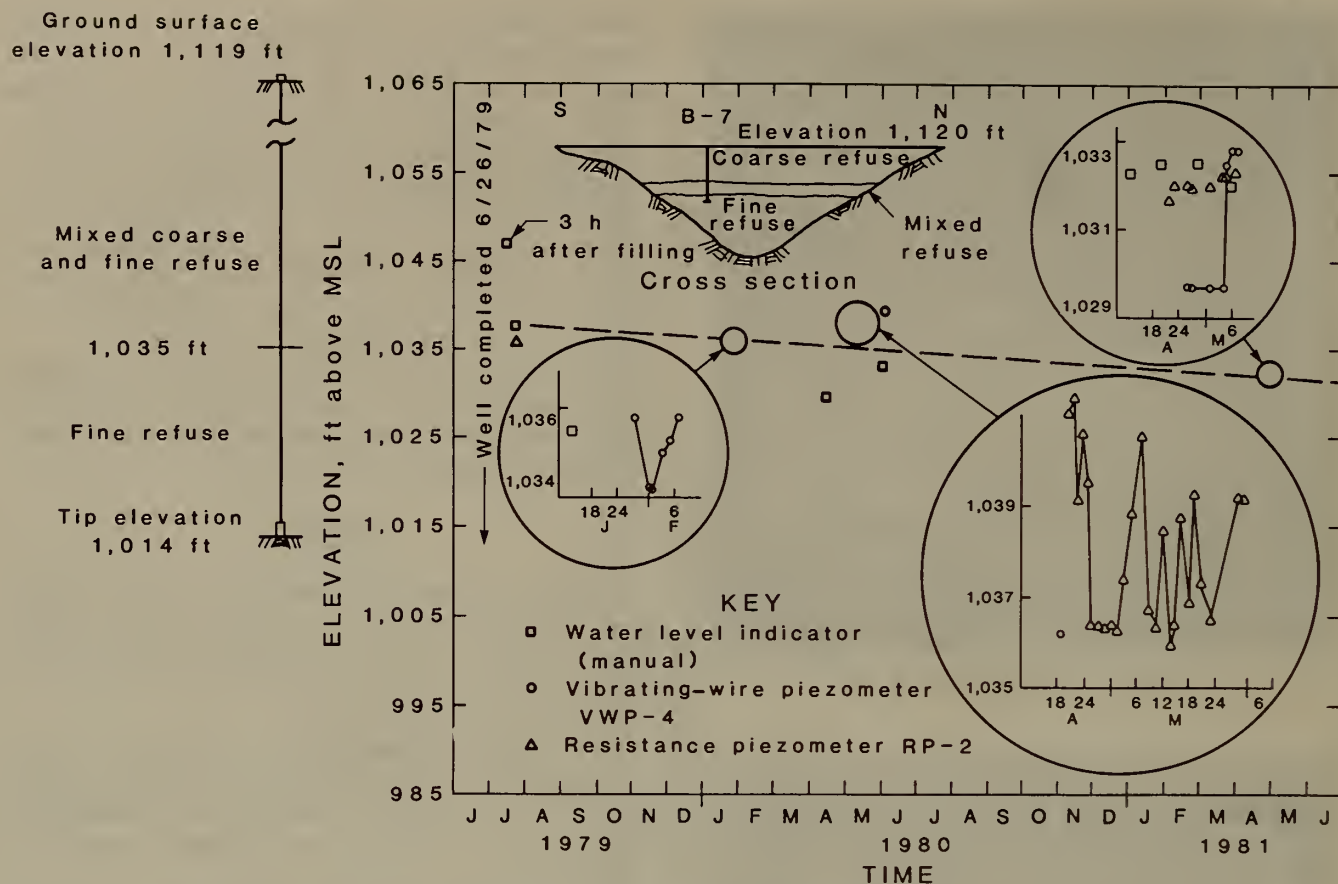


FIGURE 19.—Water levels for piezometer B-7.

TABLE 5. - Cost analysis of manual and remote monitoring systems (1982 costs) (4)

Cost item	Manual ¹	Automatic
System design.....	\$10,000	\$20,000
Capital (equipment, instruments, cable, etc.).....	62,000	85,000
Installation labor.....	60,000	73,000
Subtotal installation costs.....	132,000	178,000
Maintenance costs.....per year..	2,000	20,000
Monitoring labor, per set ²	116	15
Data processing labor, per set ²	58	Nap
Data processing labor (1st year only) ³	Nap	5,000
Data interpretation.....per year..	10,000	10,000

Nap Not applicable.

¹Manual costs calculated from automated system costs.²Based on labor rate of \$29/h.³No data processing labor costs after initial year of operation.

NOTE.--All costs based on 37-sensor system.

would be economical for less frequent monitoring. A large number of instruments were used for this project to determine possible installation problems and the long-term reliability of the various instruments on the market. Costs in a real situation would be lower because only three to six instruments would be required.

PHASE 2. - IN SITU INSTRUMENTATION WITH SATELLITE TRANSMISSION OF DATA

In phase 2, a contract was awarded to Energy, Inc. (7), to demonstrate a self-contained satellite communication link and data collection platform (DCP) that remotely monitored the stability and seepage instrumentation located on the coal waste embankment at the Armco No. 7 coal mine, Montcoal, WV. The costs, ease, and accuracy of data transmission,

and maintenance and instrumentation problems of phases 1 and 2 were compared.

Description of Work

Because the instrumentation from phase 1 was already in place on the embankment, only the data collection and transmission system had to be selected and installed on-site, together with the instrument interface circuitry. The GOES East satellite was selected to relay data from the test site DCP to the user's terminal via the Command and Data Acquisition Station (CDA) and the Data Collection System-Data Processing System (DCS-DPS). The data were then reduced and plotted for study.

Equipment and Instrumentation

A Sutron 8004B DCP was selected because of its low power consumption, 16 analog or digital parameter inputs, and availability. Additional equipment included a 12-V storage battery, two Solarex 4200EG solar panels, and a six-element Yagi antenna. The DCP, solar panels, and antenna were mounted on a support pole with the solar panels aligned for optimum solar illumination supply (fig. 21) and the antenna aligned with the GOES East satellite.

The previously installed instrumentation continued to monitor the coal waste embankment and its environmental characteristics. However, technical difficulties limited the final setup to 10 instruments of 3 types--the weir, the rain gauge, and 3 multiposition borehole extensometers (1-4, 2-2, 3-2)--plus a thermocouple. A vibrating wire piezometer had also been planned, but the interface was continually nonfunctioning owing to line transient damage.

To make this a completely self-contained communication system, the data had to be transmitted via satellite to a receiving station. For this purpose the GOES East satellite was selected. It is

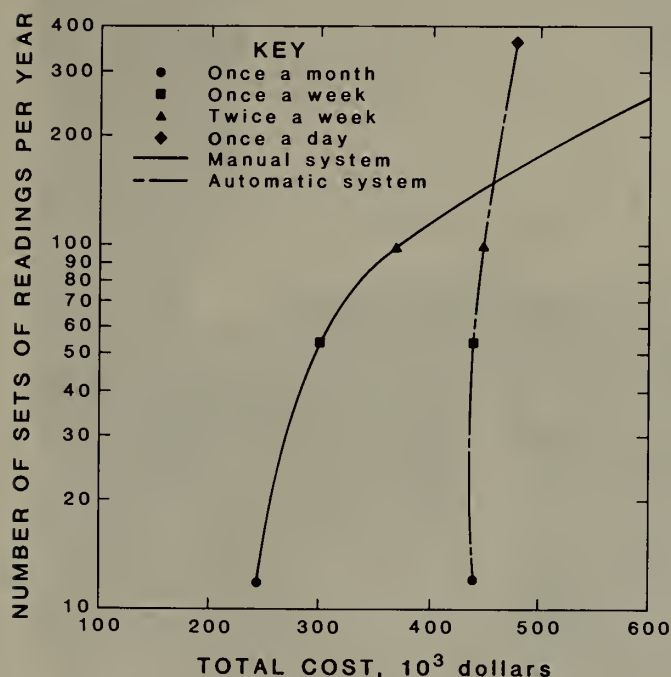


FIGURE 20.—Monitoring costs as a function of number of readings. Costs based on 37-sensor system with a total life of 8 yr.



FIGURE 21.—Data collection platform, solar panels, Yagi antenna.

operated without charge by the National Oceanic and Atmospheric Administration-National Earth Satellite Service (NOAA-NESS) (5) for the acquisition of environmental data, provided that the data can be disseminated to other interested parties. The system data flow consisted of four major subsystems: (1) sensor data collection, (2) data transmission from the DCP to GOES, (3) data retrieval from GOES and storage by NOAA-NESS, and (4) dissemination and processing of retrieved data.

The DCP received and stored data from the various analog sensor data lines on a preprogrammed collection interval. Data transmission to the GOES satellite occurred on a specific NOAA-NESS allocated

channel frequency in a self-timed transmission mode at 4-h intervals. The GOES satellite in turn transmitted to the CDA station ground equipment, which decoded the data and checked for errors. The data were then transmitted via conditioned leased lines to the DCS-DPS, which acted as a central data distribution facility by storing the data in user queues and providing the user with interfacing for data requests. The user acquired the data from the DCS-DPS via a standard telephone link (fig. 22).

Data from the DCS-DPS were reproduced as hard copy and manually reduced, until the programming for the automated data dissemination could be completed for the Chromatics GG1999 computer. Completion

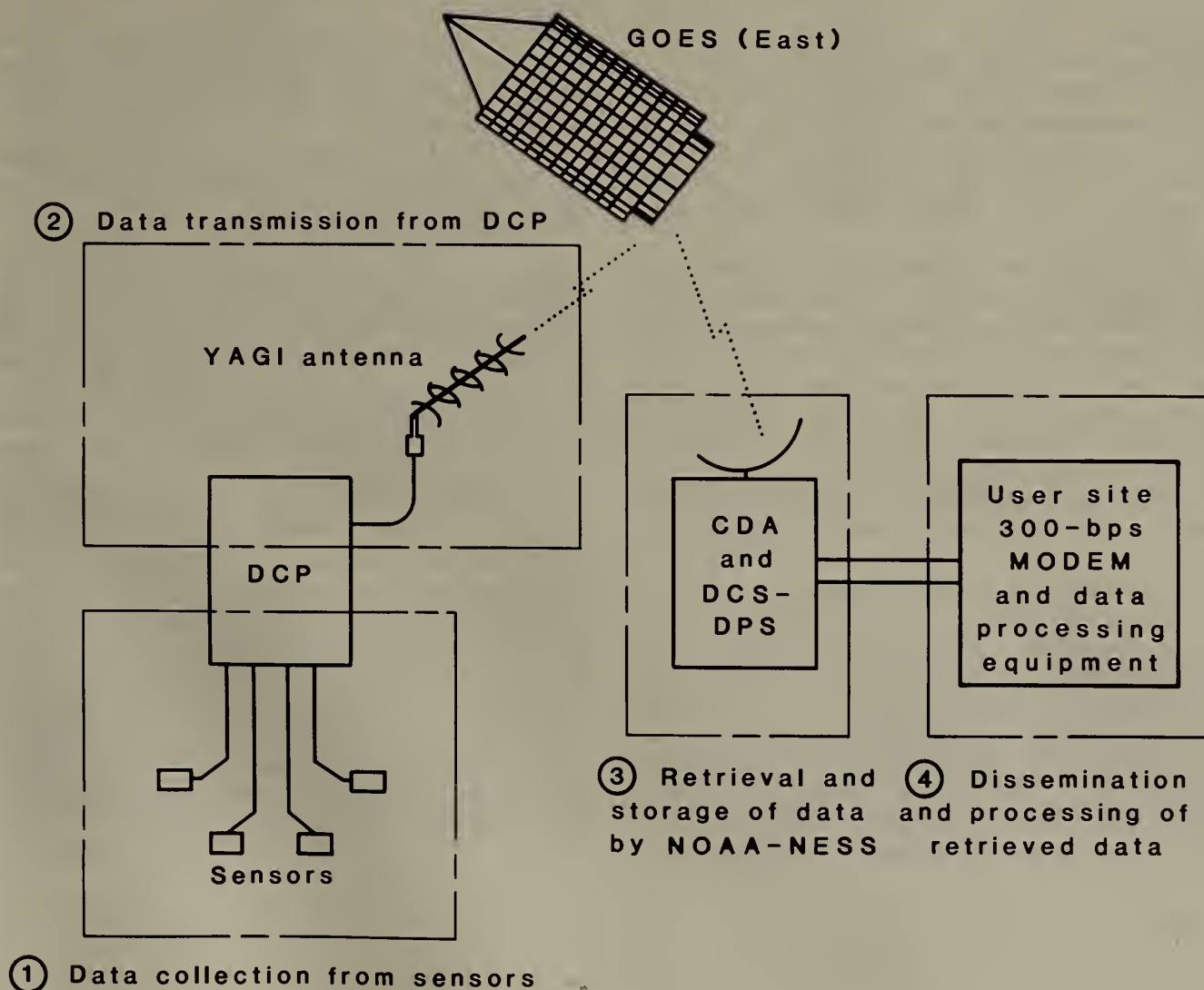


FIGURE 22.—System data flow.

of this task allowed for data storage on 8-in floppy disks from which graphs could be plotted in engineering units.

Results

Complete data and results of this study are described in more detail in the contract report (7). Although data collection systems consisting of the DCP satellite and ground station receivers have been widely used to successfully monitor environmental conditions (rain, wind, and temperature) for flood control and on buoys at sea, their use for monitoring embankment instrumentation had never previously been documented. Major findings included--

1. The reliability of the system was very high. The DCP required no preventive maintenance, and trips to the site in the event of a failure were rare. Data transmission had an error rate of 0.31%, mostly due to a duplicate channel frequency time slot assignment. Otherwise, the error rate would have been 0.0635%.

2. Though the initial cost of the system is high (table 6), it is still lower than that of the phase 1 system; also, the system is easier to operate and maintain, and it requires neither power lines or telephone lines into the site nor a building to house the DAS. Therefore, solar-powered data collection is a reliable and cost-effective method to monitor sensors at a remote waste embankment site.

3. Great care must be taken in selecting the site sensors and placing them in the embankment. This appears to be the limiting factor in the use of this system, and the major reason for downtime and the limited amount of data collected. The tiltmeters, inclinometer, and piezometers were difficult to maintain over a long-term period, in part because these were electrical instruments working in a

harsh environment and in part because the impoundment was in a continual state of construction and maintenance.

RECOMMENDATIONS--PHASES 1 AND 2

As a result of the data compiled in phases 1 and 2, there are five recommendations with regard to the overall system and its geotechnical instrumentation:

1. The system should be flexible enough to accept a number of different sensor types.

2. Further development in geophysical instruments is needed, specifically in inclinometers, tiltmeters, extensometers, and piezometers, to make them more reliable, cheaper, and easier to install and maintain.

3. A standard remote monitoring system applicable to coal and metal and nonmetal waste impoundments and embankments should be developed.

4. Satellite data transmission should be investigated if more than 10 sites are to be instrumented.

5. This method of remote data collection could be used by MSHA, mining companies, or public utilities to centrally monitor the stability of one or more impoundments. It would be most effective either in populated areas with high overall precipitation rates or local periods of sudden extreme precipitation rates (hazardous situations), or in remote areas where travel to and from a site is difficult. The system could act as an early warning device by monitoring pressure changes and movements within an embankment caused by rising water levels. It would provide more frequent readout of coal waste impoundment stability and environmental factors and would also aid in inspection and control of other disposal sites such as metal and nonmetal waste embankments or even city reservoir impoundments.

TABLE 6. - Cost comparison of satellite and telephone data transmission (1984 costs) (7)

Cost item	Unit cost	Number of units	Total cost
Satellite system:			
Data collection platform.....	\$3,725	1	\$3,725
DCP hand terminal.....	630	1	630
Environmental enclosure.....	220	1	220
Yagi antenna.....	195	1	195
Antenna cable.....	55	1	55
Solar panels.....	299	2	598
Power supply cable.....	28	1	28
Batteries (100 A·h).....	130	2	260
Wattmeter and load coil.....	250	1	250
Interface for biaxial sensors.....	3,000	1	3,000
Total for satellite system.....	NAP	NAP	8,961
Telephone system:			
Autodata 9.....	14,591	1	14,591
Signal conditioner.....	4,320	1	4,320
AC power conditioner and filtering with temperature sensor and delay.....	1,985	1	1,985
AC power conditioner.....	439	1	439
Anixter-pruzan metro tele PL1-2-2 I/F device...	123	1	123
Autodialer.....	167	1	167
Telephone modem.....	570	1	570
Power line installation and lease ³	NA	NA	NA
Telephone line installation and monthly maintenance cost ⁴	20- 100	¹ 12	240- 1,200
Trailer installation and monthly rental cost...	100	¹ 12	1,200
Total for telephone system ²	NAP	NAP	23,635-24,595

NA Not available. NAP Not applicable.

¹12 months.

²Plus costs of power line installation and lease.

³In the case of this project this system was already in place; therefore the cost was not included.

⁴Costs can vary according to length of telephone lines and weather, which can affect maintenance needs.

SATELLITE IMAGERY

A contract was awarded to Science Systems and Applications, Inc. (2), to evaluate the potential for using digital Landsat satellite data (fig. 23) for detecting active metal, nonmetal, and coal waste and tailings disposal sites to update acreage and land use information previously collected for mine waste embankment inventories (2).

DESCRIPTION OF WORK

Four mine waste disposal sites were selected: a Florida phosphate strip mine, an Arizona open pit copper mine, an Idaho underground silver mine, and a West Virginia underground coal mine. The criteria for choosing these mine sites were--

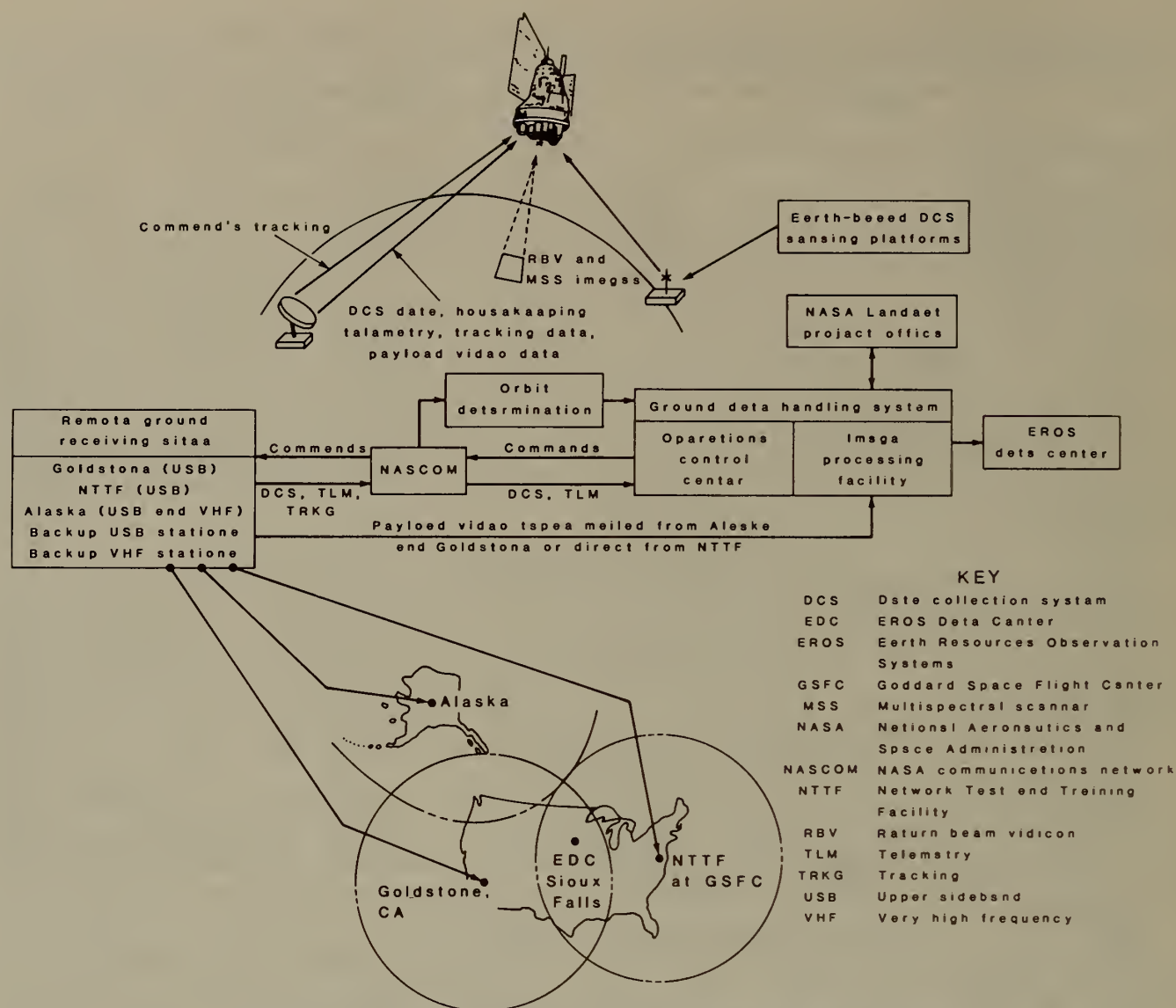


FIGURE 23.—Overall Landsat system. Source Landsat Data Users Handbook. (9)

1. An active surface or underground coal, metal, or nonmetal mining operation producing more than 500 st ore per day.

2. A diverse set of climatic conditions (wet, dry, moderate) because these could have different effects on the detectability of mine waste areas.

3. Topography because of its effect on the size and type of disposal sites available to mining operations in different parts of the country.

4. The ability to visit a selected site.

5. Ease of obtaining aerial photography and accompanying Landsat data; these can be affected by cloud cover, sun

angle, season, currency of the information, and how closely the dates could be matched for the two types of data.

6. Availability of updated topographic maps.

7. Availability of road maps.

8. Availability of USGS orthophoto-quadrangle maps.

Based on the site selection data, the chosen sites ranged from a valley fill in West Virginia to a flat diked embankment in Florida to a terraced embankment in Arizona. Other mine waste sites were also located nearby for signature extension testing. This technique was used to

check that the procedures used to study one site could be extended to other mine sites in the same locality.

Selection of aerial photography and Landsat data was based on the image quality of the data, the time of year, the time of day, and the degree of cloud cover. Most important was the need for recent coverage (after Feb. 1, 1979) because of site changes at active mine locations. Also necessary was the availability of at least same-year coverage by both aerial photography and Landsat, preferably as close together chronologically as possible.

EQUIPMENT AND PROCEDURES

Digital data from the Landsat satellite multispectral scanner (MSS) and the General Electric Co.'s IMALE-100 system in GE's Digital Image Analysis Laboratory (DIAL) in Lanham, MD, were used to determine the capability of various image-processing techniques to monitor the waste sites. These techniques and classification methods improve the visual appearance of the image and accentuate selected features. For this study, piecewise linear contrast stretching, edge and color enhancement, and normalized and simple ratio techniques were used. Means and standard deviation were obtained for the land-use categories (waste, water, active, inactive, reclaimed) by using the raw data, enhanced by two-dimensional axis rotation, Hadamard transformation (HT), and principal-component analysis. Change detection techniques were used in the Florida phosphate region to determine their usefulness for noting changes occurring at the site during a specified time.

Each test site had four or five land-use categories, depending on the nature of the tailings and the site itself. Data analyses then consisted of comparing the various land-use categories with four classification methods using means and standard deviation, pixel count and area estimates, a classification matrix (pixel count), and classification accuracy.

The Florida phosphate mine waste test site was 40 miles east of Tampa, FL, in an area of extensive mining. Landsat

scenes for February and December 1979 and aerial photos for January and December 1979 were used to study an area of 7,607 ha (fig. 24).

The change detection studies used image differencing to note changes at the site (figs. 25-26). The greatest number of changes were noted in the active waste disposal areas in the expansion of dry waste areas and changes in the water areas.

Table 7 shows the classification accuracies of the methods used in studying the Florida phosphate mining site. From this table and from details given in reference 2, it is evident that the HT method can classify all the land-use categories, but its accuracy was poor for the "active mining" category (51%) and only fair for the "waste" category (63%). Except for the "waste" category, the raw data method classified all categories with better than 50% accuracy. The principal component analysis method was more accurate for land-use categories other than "waste" and "reclaimed."

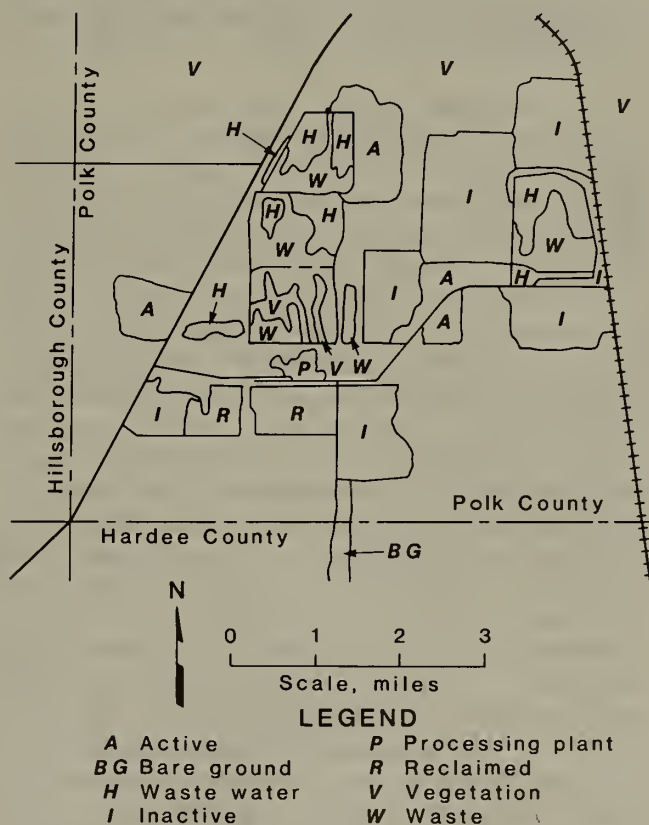


FIGURE 24.—Fort Green, FL, study area: derived from aerial photography.

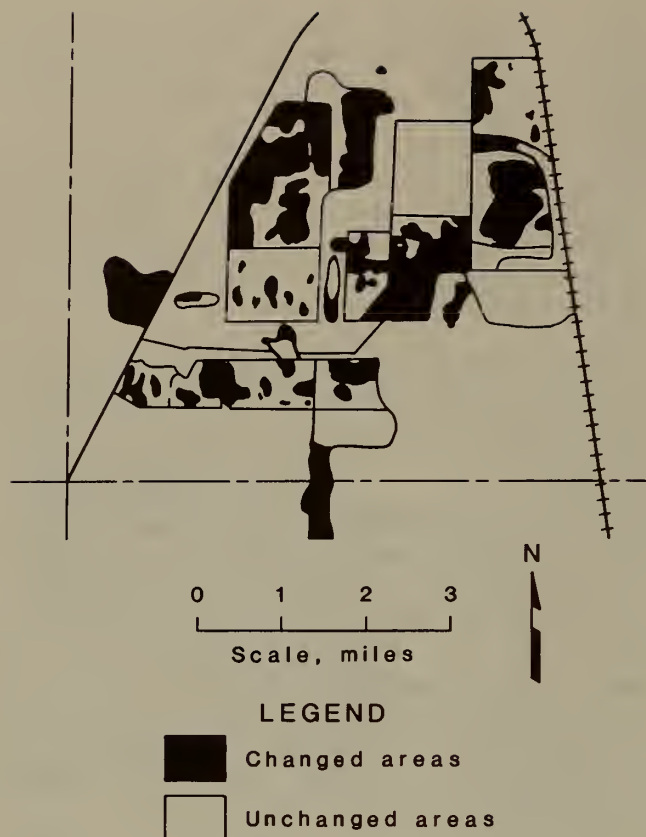


FIGURE 25.—Fort Green, FL, study area: automated change detection.

Two tailings areas were studied at copper mines in Arizona: one at Hayden and one at Miami. A Landsat scene for July 1979 and aerial photos for April 1979 and February 1980 were used to study areas of 500 ha at Hayden and 2,000 ha at Miami. The classification accuracy tables (table 7) for each site showed that the overall accuracies for all classification methods were not very good. For the Hayden site, simple and normalized ratio methods worked best, while for the Miami site the raw data and HT methods were the best.

The waste embankments from two Coeur d'Alene silver mines in Idaho were also used for this study. Data from these embankments were combined since one of the embankments was too small for individual analysis. Landsat scenes for June 1979 and aerial photos for July 1980 and August 1977 created inconsistencies due to the large time interval between the dates. The most accurate method for this study area (table 7) was two-dimensional axis rotation; tailings and water were

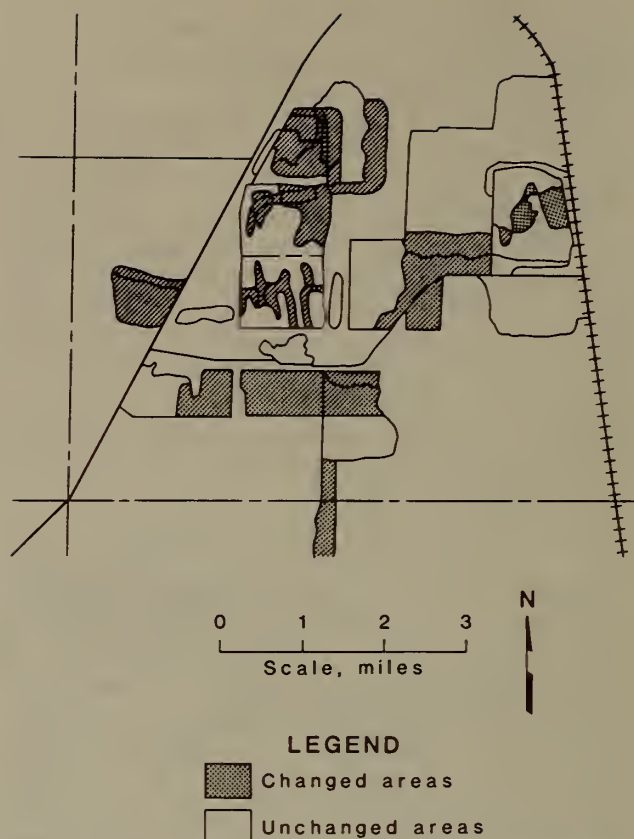


FIGURE 26.—Fort Green, FL, study area: manually interpreted.

the most inconsistently classified categories owing to their spectral reflectance complexity.

A West Virginia coal mine having a 9.7-ha, valley-fill waste embankment with a water impoundment was selected for the coal waste test site. Landsat scenes for July 1980 and aerial photos for April 1980 were used for the study. The raw data method (table 7) was the most accurate classification method for this site.

RESULTS

Complete data and results of this study are described in more detail in the contract report (2). The most significant factors were--

1. No single automated digital image processing technique would work consistently and accurately at each site. The wide range of waste materials at a site, the use of processed wastes for construction of roads and fill, color variations

TABLE 7. - Classification accuracy of methods used to study five waste areas, percent (2)

Land-use category	Raw data	Sample ratio	Normalized ratio	2-D rotation	Hadamard transform	Principal component analysis
FLORIDA PHOSPHATE MINING AND WASTE AREA						
Waste.....	21.0	NAp	NAp	50.1	62.7	49.1
Water.....	86.0	NAp	NAp	94.8	75.9	91.2
Active mining.....	55.9	NAp	NAp	44.4	51.0	66.1
Inactive mining....	68.8	NAp	NAp	63.2	81.1	85.3
Reclaimed.....	86.9	NAp	NAp	0	60.0	0
COPPER MINING AND WASTE AREA, MIAMI-CLAYPOOL, AZ						
Light tailings.....	67.9	41.3	40.6	66.8	67.3	71.7
Dark tailings.....	43.3	79.0	43.5	52.2	23.3	6.4
Waste rock.....	26.7	12.2	49.5	14.8	45.1	22.4
Water.....	75.8	56.2	71.1	66.3	69.5	67.7
COPPER MINING AND WASTE AREA, HAYDEN, AZ						
Dark tailings.....	55.6	68.1	64.5	66.6	60.0	52.8
Water.....	72.9	98.6	100.0	74.3	75.7	70.0
IDAHO SILVER MINING AND WASTE AREA						
Tailings.....	25.0	81.6	66.3	85.2	11.7	74.5
Slag.....	77.1	51.4	62.9	100.0	74.3	97.1
Gypsum.....	100.0	78.3	73.9	84.8	76.1	78.3
Water.....	70.1	61.2	67.2	80.6	59.7	61.2
Bare ground.....	90.3	80.8	83.9	95.1	79.2	89.1
WEST VIRGINIA COAL MINING WASTE AREA						
Refuse.....	89.5	80.7	84.2	89.5	75.4	56.1
Water.....	88.9	66.7	55.6	66.7	55.6	55.6
NAp Not applicable.						

in the ponds and embankments due to the mining of different ores as well as varying moisture content, and reflectance variance in the ponds themselves due to silting or depth all contribute to creating a complex and dynamic environment. The subtle differences that result make it difficult to extend a signature from one mine site to another.

2. It is not possible with current state-of-the-art digital processing techniques to inventory mine waste embankments on a national basis using satellite imagery.

RECOMMENDATIONS

Based on the results from this satellite imagery study, the following recommendations are made:

1. Use of digital data from the thematic mapper in Landsat 4 could be more useful because the mapper has a higher resolution.

2. Manual interpretation of enlarged Landsat images used in conjunction with auxiliary information might be a useful supplement to updating mine waste inventories.

SUMMARY AND CONCLUSIONS

This report summarizes five contracted projects dealing with remote sensing of coal waste embankments. Three different forms of remote sensing were studied: aerial monitoring, remote data transmission from in situ instrumentation, and satellite imagery. Aerial monitoring

study 1 investigated the use of aerial photography and photogrammetry on an actively moving landslide and on two coal embankments. Survey targets were installed on the moving face, and subsequent photoreconnaissance measured the targets' movements. Aerial monitoring

study 2 investigated the use of survey targets installed off the embankment faces of 15 coal waste sites in West Virginia and Kentucky. Placing the targets off the active areas of the embankments required more complex equipment and data analyses but protected the targets from incidental movement and destruction. Phase 1 of in situ instrumentation investigated the use of internally emplaced instruments to monitor embankment conditions and transmitted the data by telephone to another geographic region. Phase 2 used the same internally instrumented embankment but transmitted data through a satellite link to a receiving station which then could be accessed by telephone. Satellite imagery used digital Landsat satellite data to evaluate active coal, metal, and nonmetal waste sites to update mine waste embankment inventories.

In aerial monitoring study 1 it was found that the costs of such a monitoring technique were up to three times those of existing conventional inspections. However, the benefits of having objective documentation, such as aerial photographs or photogrammetric maps, produced over a period of time could not be estimated. Because the targets were located within the area under study, they proved susceptible to incidental movement, damage, or loss.

Aerial monitoring study 2 differed from study 1 in the placement of the targets and the mode of calculating movement. The targets were placed outside the area of interest, and computer-aided stereo-plotters were used to measure movement on the embankment. This protected targets from damage and loss due to incidental movement or construction activity. The disadvantage of placing the target off the active area proved to be decreased visibility due to snow and growing vegetation. The cost of this technique was estimated to be 17% to 30% higher than existing inspection costs.

In in situ instrumentation, phase 1 featured remote data collection by

telephone. This project suffered numerous disruptions caused by local power failures and downed telephone lines. Cost estimates for such a technique, including internal instrumentation in the embankment consisting of 37 sensors, ranged from \$144,174 for a manually read system to \$213,015 for an automatic system.

Phase 2 used the same internal instruments and embankment as phase 1, but the data were relayed via satellite to a receiving station which was then accessed by the user via telephone. The solar-powered data collection platform, the satellite antenna, and the use of the satellite to relay data proved very reliable. Costs to install a satellite system equalled \$8,961, compared to \$24,595 for a telephone system. These estimates did not include costs for the system design and the embankment instruments or their installation, and access to the satellite was free.

Mine waste location by satellite imagery was an ineffective means to update mine waste inventory data. At the time of the study, satellite sensors were not sufficiently sensitive to detect color changes due to differing mineral compositions at the various waste locations.

The remote sensing techniques studied could be used to supplement existing monitoring efforts and to provide visual, historical documentation. Aerial photography can be used to characterize the overall conditions at the embankment surface (seeps, slumps, fire, drainage effectiveness, etc.). Use of aerial photogrammetry can quantitatively document surface movement over time. This could be especially useful in determining embankment creep or swelling, or in estimating volume. Internal embankment conditions can be closely monitored using in situ instrumentation (extensometer, piezometer, inclinometer, thermocouple, etc.) in conjunction with the GOES satellite. It would then be possible to initiate internal embankment readings and to transmit instrument data whenever needed.

REFERENCES

1. American Society of Photogrammetry (Falls Church, VA). Manual of Remote Sensing. V. 1-2, 1975, 2144 pp.
2. Anuta, M. A., and O. P. Bahethi. Mine Waste Location by Satellite Imagery (contract J0208030, Science Systems and Applications, Inc.). BuMines OFR 134-83, 1982, 100 pp.; NTIS PB 83-238519.
3. Campbell, P. M., and R. G. Almes. Modification to Existing Coal Refuse Disposal Facility, Lower Big Branch, Montcoal, Raleigh Co., WV. D'Appolonia Consulting Engineers, 1978, 23 pp.
4. Green, G. E., and D. A. Roberts. Remote Monitoring of a Coal Waste Impoundment in West Virginia (contract H0282041, Shannon & Wilson, Inc.). BuMines OFR 79-83, 1982, 175 pp.; NTIS PB 83-196584.
5. MacCallum, D. H., and M. J. Nestle-bush. The Geostationary Operational Environmental Satellite Data Collection System. NOAA Tech. Memo. NESDIS, 1983, 49 pp.
6. Meisher, R. A., and R. L. Hoffman. Improving Surface Coal Refuse Disposal Site Inspections (contract J0188027, Chicago Aerial Survey). BuMines OFR 54-81, 1980, 297 pp.; NTIS PB 81-215402.
7. Prokoski, F. J., J. T. Byrne, and D. J. Bryant. Satellite Monitoring for a Coal Waste Embankment (contract H0212017, Energy, Inc.). BuMines OFR 102-85, 1984, 100 pp.
8. Roth, L. H., J. A. Cesare, and G. S. Allison. Rapid Monitoring of Coal Refuse Embankments (contract H0262009, CH2M Hill). BuMines OFR 11-78, 1977, 113 pp.; NTIS PB 277 975/AS.
9. U.S. Geological Survey. Source Landsat Data Users Handbook. Revised edition, 1979.

BIBLIOGRAPHY

- Ahmad, M. V., D. A. Kanter, and J. W. Antalovich. Mapping of Spoil Banks Using ERTS-A Pictures. Paper in Remote Sensing of Earth Resources, ed. by F. Shahrokhi (Proc. 2d Conf. on Earth Resources Observation and Information Analysis Systems, Tullahoma, TN, Mar. 26-28, 1973). Univ. TN Space Inst., v. 2, 1973, pp. 1073-1093.
- Albright, J. N., P. M. Halleck, C. Pearson, and M. Fehler. Subsurface Subsidence Damage Monitoring: Seismic Tomography and Microgravimetry. Paper given at workshop on Surface Subsidence due to Underground Mining, Morgantown, WV, Nov. 24, 1981, unpublished, CONF-811173-2, 9 pp.; NTIS PC A02/MF A01, DOE DE82010395.
- Alexander, S. S., J. Dien, and D. P. Gold. The Use of ERTS-1 MSS Data for Mapping Strip Mines and Acid Mine Drainage in Pennsylvania. Paper in Proceedings of Symposium on Significant Results Obtained From ERTS-1 (Goddard Space Flight Center, New Carrollton, MD, Mar. 5-9, 1973). NASA SP-327, v. 18, 1973, pp. 569-576.
- Alger, L. H., P. W. Mausel, and R. R. Herner. Identification of Surface-Disturbed Features Through Isurs1 Non-Parametric Analysis of Landsat MSS Data. Paper in Machine Processing of Remotely Sensed Data (5th Annu. Symp., Purdue Univ., West Lafayette, IN, June 27-29, 1979). IEEE (Cat. No. 79CH1430-8 MPRSD), New York, 1979, pp. 172-182.

Amato, R. V., O. R. Russell, C. E. Weir, and F. J. Wobber. Application of ERTS-A Imagery to Fracture Related Mine Safety Hazards in the Coal Mining Industry. Coal Sec., Indiana Geol. Surv., Bloomington, IN, ERTS Prog. Off., NASA Goddard Space Flight Center, Greenbelt, MD, Rep. NAS5-21795, Jan.-July 1973, 136 pp.; NTIS N73-27252.

American Society of Civil Engineers. Recent Developments in Geotechnical Engineering for Hydro Projects: Engineering Geology Aspects, Rock Mechanics Studies and Embankment Dam Instrumentation. New York, 1981, 250 pp.

Anderson, A. T. Evaluating the Environmental Effects of Past and Present Surface Mining - A Remote Sensing Applied Research Review. Paper in Proceedings of the Fourteenth International Symposium on Remote Sensing of the Environment. Environ. Res. Inst. MI, Ann Arbor, MI, v. 1, Apr. 1980, pp. 275-278.

Anderson, A. T., D. T. Schultz, and N. Buchman. Landsat Inventory of Surface-Mined Areas Using Extendable Digital Techniques: Monitoring Surface Mines From Space. Final Report, NASA/Goddard Space Flight Center, Greenbelt, MD, June 30, 1975, 44 pp.

Anderson, A. T., D. Schultz, N. Buchman, and M. Nock. Satellite Data for Surface-Mine Inventory. Photogrammetry Eng. and Remote Sensing, v. 43, 1977, pp. 1027-1036.

Anderson, A. T., and J. Schubert. ERTS-1 Data Applied to Strip Mining. Photogrammetry Eng. and Remote Sensing, v. 42, 1976, pp. 211-219.

Aronoff, S., G. A. Ross, and W. A. Ross. Environmental Monitoring of the Athabasca Oil Sands Using Landsat Data. Photogrammetria, v. 38, Oct. 1982, pp. 77-86.

Bailey, D. J. Land Movement Monitoring System. Bull. Assoc. Eng. Geol., v. 17, No. 4, 1980, pp. 213-221.

Ballew, G. Alteration Mapping at Goldfield, Nevada, by Cluster and Discriminant Analysis of Landsat Digital Data. Paper in Proceedings of the Eleventh International Symposium on Remote Sensing of the Environment. Environ. Res. Inst. MI, Ann Arbor, MI, Apr. 1977, pp. 783-790.

Barr, D. J. Landsat Applications to Surface Mining. Paper in Proceedings of the First International Conference on Computers in Civil Engineering (New York, NY, May 12-14, 1981). ASCE, 1981, pp. 384-396.

Bayne, J. N., and H. Lawrence. Application of Satellite Data to Surface Mine Monitoring in Selected Counties of South Carolina. BuMines OFR 11-80, 1979, 141 pp.; NTIS PB 80-144629.

Boldt, C. M. K., and B. J. Scheibner. Application of Remote Sensing for Coal Waste Embankment Monitoring. Paper in Mine Waste Disposal Technology (Proc. BuMines Technol. Transfer Workshop, Denver, CO, July 16, 1981). BuMines IC 8857, 1981, pp. 40-45.

Borden, F. Y., B. F. Mermbeck, D. N. Thompson, B. J. Turner, and D. L. Williams. Classification and Mapping of Coal Refuse, Vegetative Cover Types, and Forest Types by Digital Processing of ERTS-1 Data. Paper in Proceedings of the Ninth International Symposium on Remote Sensing of the Environment. Environ. Res. Inst. MI, Ann Arbor, MI, v. 1, 1975, pp. 133-151.

Budge, T. K. Development of an Image Processing System at the Technology Applications Center, UNM: Landsat Image Processing in Mineral Exploration and Related Activities. NM Energy & Minerals Dep., Santa Fe, NM, Final Rep. EMD-78-1138, Sept. 1980, 73 pp.

Butterworths. Field Instrumentation in Geotechnical Engineering. London, 1974, 720 pp.

Carneggie, D. M., and D. O. Ohlen. A Selected Bibliography: Remote Sensing Techniques for Evaluating the Effects of Surface Mining. Technicolor Graphic Services, Inc., Sioux Falls, SD, Mar. 1979, 15 pp.

Carneggie, D. M., J. A. Sturdevant, W. G. Rohde, D. O. Ohlen, C. A. Nelson, J. C. Taranik, J. R. Lucas, and F. C. Billingsley. Assessing the Impact of Surface Mining. U.S. Geol. Surv. Prof. Paper 1100, 1978, pp. 304-305.

Chase, P. E., and W. Pettyjohn. ERTS-1 Investigation of Ecological Effect of Strip Mining in Eastern Ohio. Paper in Proceedings of Symposium on Significant Results Obtained From ERTS-1 (Goddard Space Flight Center, New Carrollton, MD, Mar. 5-9, 1973). NASA SP-327, v. 1, 1973, pp. 561-569.

Curtis, E. I. Strategy for Remote Sensor Use in Mining, Hydrology, and Pollution Control. Paper in Technology Utilization Ideas for the 70's and Beyond (Proc. Spec. AAS-AIAA Tech. Event, Winrock, AR, Oct. 30, 1970). AAS Sci. Technol. Ser., v. 26, 1971, pp. 301-315.

Earth Satellite Corp. Use of Photo Interpretation and Geotechnical Data in the Identification of Surface Damage and Subsidence. Apr. 1975, 246 pp.; NTIS, PB 242468.

Elifrits, C. D. Study of Subsidence Over a Room and Pillar Coal Mine. Ph.D. Thesis, Univ. MO, Rolla, MO, 1980, 130 pp.; Univ. Microfilms Order No. 81-02,271.

Gilbertson, B. Monitoring Vegetation Cover on Mine Dumps With ERTS-1 Imagery: Some Initial Results. Paper in Proceedings of a Symposium on Significant Results From ERTS-1 (Goddard Space Flight Center, New Carrollton, MD). NASA SP-327, v. 1, 1973, pp. 577-584.

Glass, C. E., and R. A. Schowengerdt. Application of Digital Image Analysis to

Mined Lands Reclamation. Soc. Min. Eng. AIME, 1979, pp. 16-24.

Glass, C. H., R. A. Schowengerdt, and J. R. Carr. Inventory and Hazards Monitoring of Mined Lands Using Automated Processing of Satellite Imagery and Collateral Data. Office of Surface Mining, Reclamation and Enforcement, Final Rep. MGEN-79-16F, 1980, 115 pp.

Gonzales, R. W., and M. H. Inglis. Remote Sensing of Natural Resources. Quarterly Literature Review, July-Sept. 1980. Univ. NM, Albuquerque, NM, Technol. Application Center, Report TAX-RS-80-003, 1980.

Green, G., and D. A. Roberts. Remote Monitoring of a Coal Waste Impoundment in West Virginia, (contract H0282041, Shannon & Wilson, Inc.). BuMines OFR 79-83, 1980, 173 pp.; NTIS PB 83-196584.

Hampel, D. Advanced Remote Expendable Sensor/Processing Techniques. Paper in Proceedings, AIAA Sensor Systems for the 80's Conference (Colorado Springs, CO, Dec. 2-4, 1980). AIAA, New York, 1980, pp. 104-108.

Hardaway, T. E. Surface Coal Mining in the Northern Great Plains of the Western United States. An Introduction and Inventory Utilizing Aerial Photography Collected in 1974 and 1975. EPA, Rep. EPA/OEA-76/1, June 1976, 198 pp.

Henkes, W. C. Satellite Monitoring of Open Pit Mining Operations. BuMines IC 8530, 1971, 28 pp.

Hundemann, A. S. Strip Mining (citations from the NTIS Data Base, v. 2, 1976-Nov. 1979). IL Nat. History Surv., Jan. 1980, 255 pp.; NTIS, PB-80-803570.

Inglis, M. H. Development of a Coal Surface Mine Monitoring Capability Utilizing Landsat Satellite Technology. Available from Technol. Application Center, Univ. NM, Albuquerque, NM, 1980, 39 pp.

Inglis, M. H., H. W. Sheffer, R. J. P. Lyon, and A. E. Prelat. Landsat Monitoring of the Navajo Coal Surface Mine. Paper in Proceedings of the American Society of Photogrammetry (Fall Tech. Meeting, Albuquerque, NM, Oct. 15-20, 1978). Am. Soc. Photogramm., Falls Church, VA, 1978, pp. 523-539.

Irons, J. R., H. Lachowski, and C. Peterson. Remote Sensing of Surface Mines; A Comparative Study of Sensor Systems. Paper in Proceedings of the Fourteenth International Symposium on Remote Sensing of the Environment. Environ. Res. Inst. MI, Ann Arbor, MI, v. 2, Apr. 1980, pp. 1041-1053.

Ishikawa, P., Jr., and G. A. Shelton. Summary of the Western Energy Overhead Monitoring Project (EPA contract 68-03-2636, Environ. Monitoring and Support Lab., Las Vegas, NV). EPA Rep. EPA-600/4-80-051, Oct. 1979, 38 pp.

Johannsen, C. J., R. W. Blancher, and D. J. Barr. Characteristics of Properties of Strip Mine Spoils as Related to Remote Sensing Measurement (Univ. MO, Columbia Campus Agr. Exp. Station, Dep. Agronomy, Columbia, MO, contract/grant No. 0073683, M000354-1). U.S. Dep. Agriculture, Cooperative Res. Office, Columbia, MO, 1981.

Knuth, W. M., E. L. Fritz, and J. A. Schad. Investigation of Color and Color Infrared Aerial Photographic Techniques for Mining and Reclamation Planning and Monitoring (contract J0155041, HRB-Singer, Inc., State College, PA). Bu-Mines OFR 37-79, 1978, 215 pp.; NTIS PB-294707.

Knuth, W. M., Jr., and H. B. Charnbury. Remote Sensing Techniques for Analysis of Burning in Coal Refuse Banks. Paper in Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal (Louisville, KY, Oct. 22-24, 1974). National Coal Association, Washington, DC, 1974, pp. 38-43.

Koerner, R. M., A. E. Lord, and W. M. McCabe. Remote Sensing Applications for Mine Waste Stability Monitoring Using the Acoustic Emission Method. Paper in Proceedings International Geoscience and Remote Sensing Symposium (Washington, DC, June 8-10, 1981). IEEE Service Center (Cat. No. 81CH1656-8), v. 1, 1981, pp. 355-359.

Krumwiede, D. D. Remote Sensing Applications as Related to Surface Mining. Paper in Proceedings Symposium on Surface Mining Hydrology, Sedimentology and Reclamation (Lexington, KY, Dec. 1, 1980). Univ. KY Office Eng. Serv., 1980, pp. 159-162.

Mamula, N., Jr. Remote-Sensing Method for Monitoring Surface Coal Mining in the Northern Great Plains. J. Res. U.S. Geol. Surv., v. 6, No. 2, Mar.-Apr. 1978, pp. 149-160.

Marcus, P. M. Remote Sensing Inventory of Mining Activity in the Pennsylvania Anthracite Region. BuMines Research 76, 1976, p. 81.

Maxim, L. D., and D. E. Cullen. Cost Model for Remote Inspection of Ground Sites. Photogramm. Eng. Remote Sensing, v. 43, 1977, pp. 1009-1025.

Moik, J. G. Digital Processing of Remotely Sensed Images. NASA SP-431, 1980, 330 pp.

Moore, O. H., J. H. Adams, and A. F. Gregory. Mapping Mine Wastes With Landsat Images. Paper in Proceedings of the Fourth Canadian Symposium on Remote Sensing (Quebec, Canada, May 16-18, 1977). Canada Aeronaut. and Space Inst. Rep. A78-433 31943, 1977, pp. 294-304.

National Aeronautics and Space Administration (Cleveland, OH). LANDSAT Remote Sensing: Observations of an Appalachian Mountaintop Surface Coal Mining and Reclamation Operation. NASA-TM-84194, Oct. 1979, 7 pp.

National Field Investigations Center. Application of ERTS Technology to the Evaluation of Coal Strip Mining and Reclamation in the Northern Great Plains. Denver, CO, Feb. 1975, 120 pp.; NTIS PB-255590.

National Technical Information Service (Springfield, VA). Strip Mining. 1980-Feb. 1982 (citations from the NTIS Data Base). PB-82-807447, May 1982, 156 pp.

Patterson, D. B., and K. M. Campbell. The Effectiveness of Multi-Date, Multi-Scale Aerial Remote Sensing Imagery for Monitoring Coal Mining Operations and Reclamation Efforts in Alberta. Paper in Proceedings of the Fifth Canadian Symposium on Remote Sensing (Victoria, Canada, Aug. 28, 1978). Canada Aeronaut. and Space Inst., 1979, pp. 165-173.

Rehder, J. B. Changes in Landscape Due to Strip Mining. Paper in ERTS-1, A New Window on Our Planet. U.S. Geol. Surv. Prof. Paper 929, 1976, pp. 254-257.

Rogers, R. H., W. A. Pettyjohn, and L. E. Reed. Automated Strip Mine and Reclamation Mapping From ERTS. Paper in Proceedings, Third Earth Resources Technological Satellite-1 Symposium, ed. by S. Freden. NASA Sci. Tech. and Inf. Off., Washington, DC, NASA SP-351, v. 1, sec. B, 1974, pp. 1519-1531.

Roth, L. H., J. A. Cesare, and G. S. Allison. Rapid Monitoring of Coal Refuse Embankments (contract H0262009, CH2M Hill). BuMines OFR 11-78, 1977, 113 pp.; NTIS PB-277975.

Russell, O. R., V. Amato, and T. V. Leshendok. Remote Sensing and Mine Subsidence. Transp. Eng. J., v. 105, No. 2, Mar. 1979, pp. 185-198.

Schreier, H., and L. M. Lavkulich. Examination of the Overall Relationship Between Spectral Reflectance and Chemical Composition of 58 Mine Tailings Samples. Paper in Proceedings of the Sixth Annual Symposium--Machine Processing of Remotely Sensed Data and Soil Information Systems and Remote Sensing and Soil Survey (Purdue Univ., West Lafayette, IN, June

3-6, 1980). IEEE (Cat. No. 80CHI533-9 MPRSD), Piscataway, NJ, 1980, pp. 126-134.

Sharber, L. A., and F. Shahrokhi. Application of Satellite Data in Monitoring Strip Mines. Univ. TN Inst. Space, Remote Sensing Earth Resour., v. 6, 1977, pp. 499-514.

Solomon, J. L., W. F. Miller, and D. A. Quattrochi. Development of a Tree Classifier for Discrimination of Surface Mine Activity From Landsat Digital Data. Paper in Proceedings of the 45th Annual Meeting of the American Society of Photogrammetry (Washington, DC, Mar. 18-24, 1979). Am. Soc. Photogramm., Falls Church, VA, v. 2, 1979, pp. 607-613.

Tanner, C. E. Computer Processing of Multispectral Scanner Data Over Coal Strip Mines. Lockheed Electronics Co., Inc., Las Vegas, NV, Mar. 1979, 62 pp.; NTIS PB 80-111677.

U.S. Bureau of Mines. Fast Monitoring of Mine Waste Embankments. Technol. News, No. 67, 1979, pp. 1-2.

U.S. Environmental Protection Agency, Office of Enforcement. Remote Sensing Investigation Solid/Liquid Waste Disposal Sites. Nat. Enforcement Inv. Ctr., Denver, CO, EPA-330/1-80-002, May 1980.

U.S. Geological Survey. Use of Landsat CCT's To Inventory Kaolin Mines. Prof. Paper 1000, 1976, 271 pp.

Vanghan, P. R. The Measurement of Pore Pressure With Piezometers. Ch. in Field Instrumentation in Geotechnical Engineering. Wiley, 1974, pp. 411-422.

Wobber, F. J., C. E. Wier, T. Leshendok, and W. Beeman. Survey of Coal Refuse Banks and Slurry Ponds for the Indiana State Legislature Using Aerial and Orbital Inventory Techniques. Paper in Proceedings of the First Symposium on Mine and Preparation Plant Refuse Disposal (Louisville, KY, Oct. 22-24, 1974). National Coal Association, Washington, DC, 1974, pp. 64-77.

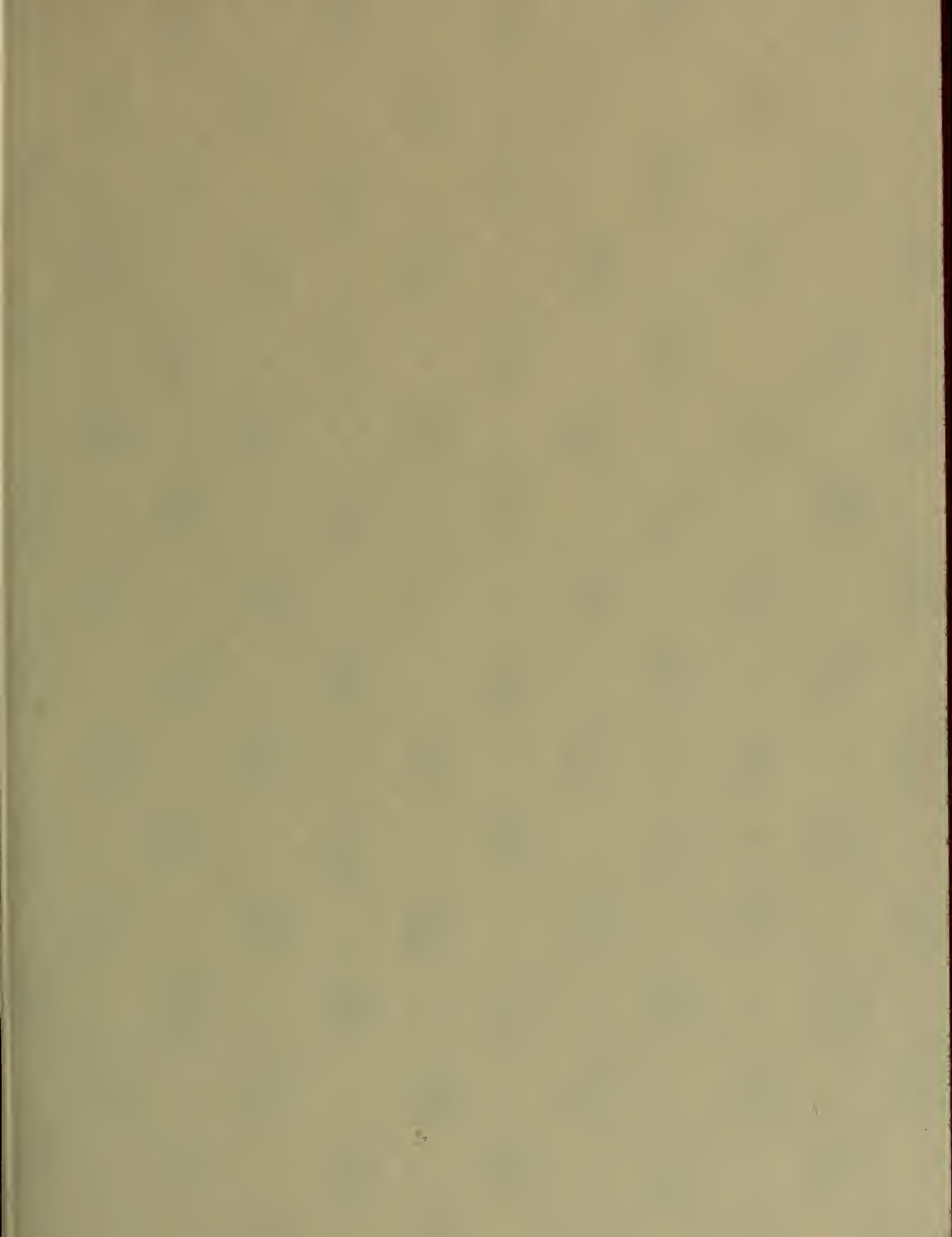


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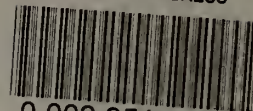






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